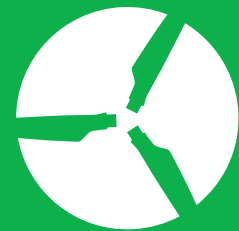


August 2019

IEA Wind TCP Task 36

**Results of IEA Wind
TCP Task 36
Forecasting for Wind
Energy, 2016-2018**



iea wind



Technical Report **iea wind**

Results of IEA Wind TCP Task 36 Forecasting for Wind Energy, 2016-2018

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Preface

This report details the main progress of Task 36 Forecasting for Wind Power during the first 3-year period of operation. 13 countries participated (see Table 1), and the mailing list comprises some 250 people from academia, met services, forecast vendors and end users.

The Task is an outgrowth of the IEA R&D Wind Task 11—Topical Expert Meeting (TEM) “Forecasting Techniques” held in April 2013 at the Federation of the Scientific and Technical Associations (FAST Center), Milan, Italy¹ and previous three Joint Action Symposiums since 2004².

Table 1 IEA Wind Task 36 Participants during the first phase, 2016-2018

Country	Contracting Party	Active Organizations
Austria	The Republic of Austria	ZAMG
China	CWEA	CEPRI, Envision, Goldwind, North China Electric Power University, Zhejiang Windey, CMA
Denmark	Danish Energy Agency	DTU (OA), WEPROG (WP Lead), DMI, ConWX, ENFOR, DNV GL, Energinet, Vestas
Germany	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	DWD (WP Lead), ZSW, energy & meteo systems, Fraunhofer IEE, ForWind, Enercon, 4cast
Finland	BusinessFinland	FMI, Vaisala, VTT
France	Government of France	MINES ParisTech (WP Lead), EDF, Engie Green, Meteolien, CNR, MeteoSwift
Ireland	Sustainable Energy Authority of Ireland	Dublin Inst. Of Technology, Cork Inst. Of Technology, Eirgrid,
Norway	Norwegian Water Resources and Energy Directorate	NMI, Kjeller Vindteknik, NORCOWE, Christian Mikkelsen Research, Equinor
Portugal	LNEG	INESC, INETI, LNEG, REN, Smartwatt, Prewind
Spain	CIEMAT	Vortex, EDP Renovaveis, CENER, Iberdrola, CIEMAT, University Carlos III, UCLM,
Sweden	Swedish Energy Agency	Vattenfall, WeatherTech, Uppsala Uni Gotland
United Kingdom	Offshore Renewable Energy Catapult	UK MetOffice, Strathclyde University, Reading University, National Grid
United States	U.S. Department of Energy	NREL (WP lead), PNNL, NOAA, NCAR, CalSO, University of Colorado Boulder, UNC Charlotte, Sharply Focused, ESIG, WindLogics

¹ IEA Wind 2013. “Forecasting Techniques”, Report: IEA R&D Wind Task 11—Topical Expert Meeting

² First joint action symposium on wind forecasting techniques. Norrköping: International Energy Agency (IEA), 2002; Second joint action symposium on wind forecasting techniques. Lyngby: International Energy Agency (IEA), 2004; IEA/POW/WOW Workshop on Optimal Use of Information in Short-Term Forecasting, September 11/12, 2008 in Madrid

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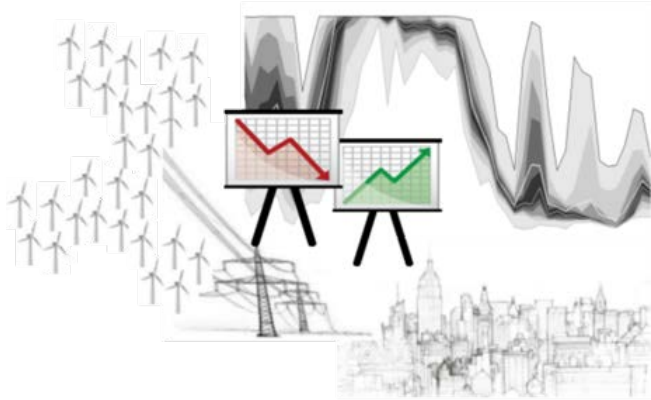
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Executive Summary

Wind energy forecasting is a technology required to efficiently integrate wind power in the electrical grid. Without forecasts, especially in countries like Denmark with 43% of wind power in the grid [IEA Annual Report], the integration of wind power would be prohibitively expensive, as far too much reserve power would have to be held available. This has been recognized early by the IEA Wind TCP, and several TEM workshops had been held between 2002 and 2008. A TEM in Milan in 2013 then paved the way to a proper task proposal. Since 2016, the interest in forecasting has been put on a new level with the start of Task 36. In this Task, some 250 people from academia, met services, forecast vendors and end users collaborate on common issues, improving the forecasts themselves and the value one can get from them.



The main result of the Task is the Recommended Practice on Forecast Solution Selection. Overall, the Recommended Practice deals with the process of choosing a new forecast solution for the end user. The three parts of the Recommended Practice deal with the selection and determination of a new forecasting system, the second part with the execution of benchmarks or trials of a new forecast vendor, and the third part explains the metrics used to assess the new solution.

Other major results are a comprehensive overview of use cases for probabilistic forecasting, an information portal on several aspects useful for wind power forecasting research, and a paper on the common workshop on minute-scale forecasting together with IEA Wind Task 32 Lidars.

In the second phase of the Task, new topics include initial thoughts on standardization, the establishment of 100-m wind speed validation at some met institutes, and uncertainty propagation through the entire model chain.

1 Background Information and Objectives of Task 36

This report describes the main findings of IEA Wind Task 36 Forecasting for Wind Power.

In general, short-term prediction of wind power on a time scale of minutes to weeks is done using online data from the wind farms to be predicted, and meteorological forecasts.

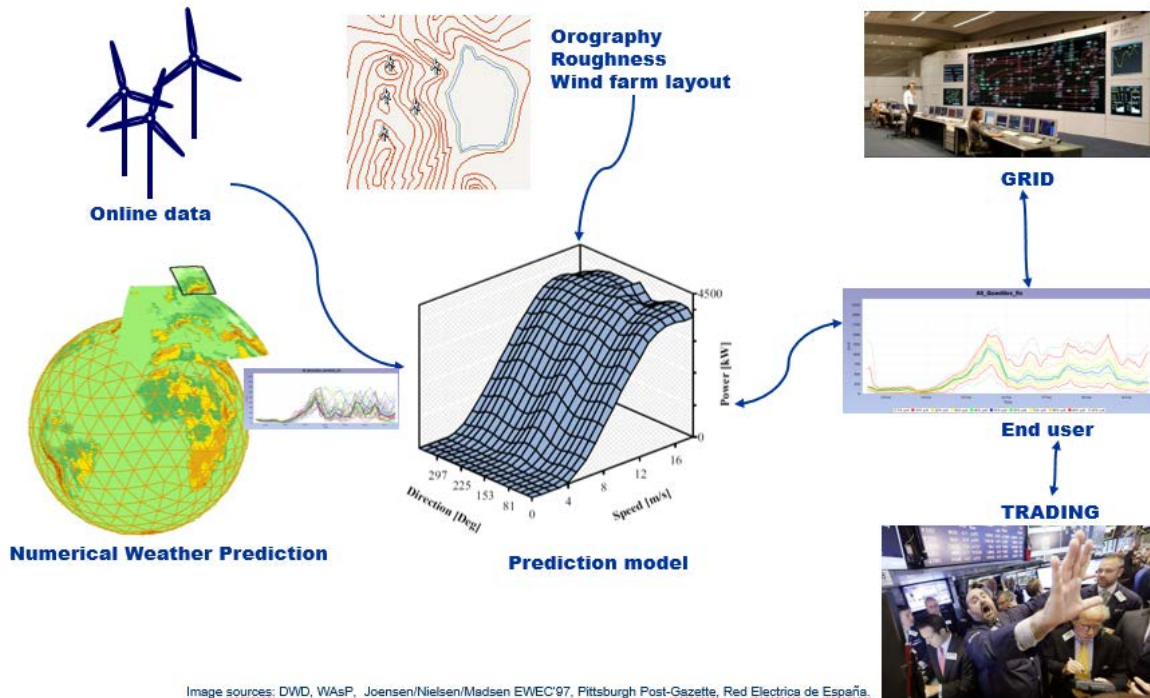


Figure 1: The flow of data through a wind power prediction system.

During the three years 2016-2018, academia, meteorological institutes, forecast vendors and end users worked together to both improve the forecasts themselves, and to improve the use of the forecasts. Hereunder we developed a Recommended Practice on how to select a forecasting solution, either as a new solution or as an additional/replacement solution. As all of the results mentioned in this report are published elsewhere already, the report should be seen as a collection of pointers to published works. This compact format is enhanced by the generation of handouts, added in the appendix. The handouts can also be used alone, and will get onto the website.

An improvement in the Numerical Weather Prediction (NWP) forecasted wind speed and direction inputs will improve the power output directly. However, currently the NWP model providers only validate their operational simulations against wind measurements at 10-m above ground, which is the standard World Meteorological Organisation (WMO) measurement height for wind speeds. However, the NWP improvements would have to be validated and optimized near the hub height of the turbines, which is closer to 100 m. The NWP data is available as a deterministic forecast (just one realization of the forecast) or an ensemble of forecasts (multiple realizations of forecasts). In the ensemble, either the initial

conditions of the forecast, or the model physics are varied, so that the variation in outcome reflects the uncertainty of the forecasts.

For the very short horizons, and in order to online tune the power forecasting models, real-time data from wind farms is used. In some cases, high-resolution modelling of the wind farm surroundings is employed. The resulting forecasts of wind speed and direction are then converted to power, typically by a 2-D estimated wind farm power curve. The results are then transferred to the end users, and used in trading, power grid management or O&M.

The work packages of the Task were aligned to the forecasting steps outlined above and in Figure 1. WP1 dealt with global coordination in forecast model improvement and therefore meteorological aspects of the forecasts, WP2 with benchmarking and power conversion aspects as well as forecast vendor aspects, and WP3 with the use of probabilistic forecasts and optimal end use of forecasts.

2 Global Coordination in Forecast Model Improvement – Meteorological Aspects of Wind Energy Forecasts

At the outset of Task 36, a complex flow workshop organized by the U.S. Department of Energy had noted that significant deficiencies remained in the NWP models used to provide wind power forecasts and characterized uncertainty quantification in these models as “immature.” At approximately the same time, an IEA Wind Technical Experts Meeting on Forecasting Techniques in Milan had noted a need for standardized methodologies to evaluate forecast performance. A primary reason for the lack of standardized approaches to NWP evaluation has been the tendency for forecasting organizations to work in relative isolation and to lack full awareness of data sources that could be used for model validation. To address these needs, this work package:

- Compiled a list of available sources of real-time data, especially from tall towers;
- Reported annually on field measurement programs that could support NWP validation; and
- Organized meetings and a special session at international conferences on wind energy.

There are two distinct needs for validation of the NWP models used for wind power forecasting. The first is applicable primarily to operational models, for which ongoing validation requires real-time data. The second is applicable to the developmental environment for updated versions of these models prior to the updates becoming operational.

Validation of operational models requires real-time data because resources generally do not permit preserving full output for extended periods or re-running the models when data from field campaigns eventually becomes available. Ideally, real-time observations of the wind at turbine heights would be reported to weather services to allow continuous monitoring and validation of NWP forecasts. In practice, very little data is provided. Thus, to more broadly facilitate the validation of NWP model forecasts of wind at turbine heights of approximately 100 m a [catalog of masts](#) with wind measurements was created. The catalog was not limited exclusively to masts providing real-time data, but most masts in the catalog are producing

data available in real time. An additional benefit of identifying sources of real-time hub-height data is their application for improving initial conditions. While this requires careful monitoring of data quality, recent research has shown the benefit of improved initial conditions for forecast accuracy.

Organizations running NWP models operationally are generally also engaged in the development of updated versions of these models, in which the representation of physical processes and the application of numerical methods are improved. Prior to becoming operational, these new versions also need to be validated. In many cases field campaigns are designed to provide validation data to researchers to illuminate specific physical processes, and for these purposes the effective measurement of key processes is more important than real-time availability. Because of the cost of field campaigns, it is important for the NWP model development community to be aware of and thus able to take advantage of existing data sets. An additional component of this work package, therefore, was to annually update a list of [significant field campaigns](#) that could support development and validation of improved NWP models. During Phase I of Task 36, there were two such campaigns: the Second Wind Forecast Improvement Project (WFIP2) in the U.S. and the New European Wind Atlas (NEWA) sequence of field studies in Europe.

A third objective of this task was to facilitate communication regarding NWP model improvement for wind power forecasting among the various international groups engaged in this area. Several informal meetings and discussions occurred around international conferences such as ICEM (International Conference on Energy Meteorology) and WESC (Wind Energy Science Conference). In addition, there was a special IEA Task 36 session at the American Meteorological Society's Eighth Conference on Weather, Climate, Water and the New Energy Economy in Seattle in January 2017. This special session featured 10 oral presentations that provided an opportunity to engage a broader community in Task 36. There was also a Mini-Symposium organized by the task on "Wind Power Forecasting" at the Wind Energy Science Conference at DTU in Lyngby, also in 2017.

3 Benchmarking, Predictability, and Model Uncertainty – Power Conversion and Forecast Vendor Aspects

The main outcome of WP2 is the publication of an IEA Recommended Practice on the Implementation of Wind Power Forecasting Solutions. The document is split into 3 parts. The first part "Forecast Solution Selection Process" deals with the selection and background information necessary to collect and evaluate when developing or renewing a forecasting solution for the power market. The second part "Benchmarks and Trials" deals with how to set up and run benchmarks and trials in order to test or evaluate different forecasting solutions against each other and the fit-for-purpose. The third part "Forecast Evaluation", provides information and guidelines regarding effective evaluation of forecasts, forecast solutions as well as benchmarks and trials and is closely connected to the work package 2.2. The work is coordinated to provide an industry recommended practice version for practical usage in relation to the implementation of forecasting solutions.



Figure 2: Recommended practices on (left) forecast solution selection process, (middle) designing and executing forecasting benchmarks and trials, and (right) evaluation of forecasts and forecast solution.

While every forecasting solution contains very individual processes and practices, there are a number of areas that all forecasting solutions have in common. For any industry it is important to establish standards and standardized practices in order to streamline processes, but also to ensure security of supply with a healthy competition structure. The Recommended Practice guideline is providing state-of-the-art practices that have been carefully collected by experts in the area and are being reviewed by professionals and experts in an appropriate number of countries with significant experience in wind energy forecasting.

The key element of the recommended practice guideline is to provide basic elements of decision support and thereby encourage forecast users to analyze their own situation and use this analysis to design and request forecasting solutions that fits their own purpose rather than applying a doing-what-everybody-else-is-doing-strategy. It is highly recommended to “engage with the forecast vendors” in order to discuss the vendors recommendations. It is often most beneficial for all parties to issue a request for information, conduct vendor meetings and explain the goal and objective of a solution and let the forecasters give their recommendations. This guideline provides therefore not only aspects for the selection process to forecast users, but also for vendors new to the market or those wanting to evolve to a new level of service and support as a guideline to state of the art practices that are recommended to be incorporated into business practices.

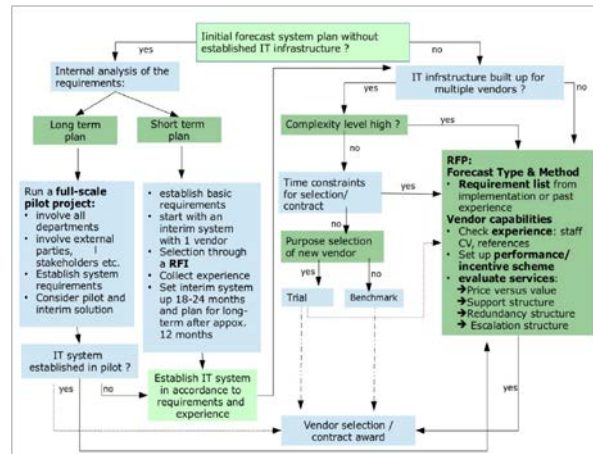


Figure 3: The flow chart for the initial deliberations of the forecast solution selection.

In the process of selecting a forecast solution, benchmark and trial exercises can consume a lot of time both for the entity conducting it (hereafter referred to as “Forecast User”) and the

participating Forecast Service Providers (FSPs). These guidelines and best practices are based on years of industry experience and intended to achieve maximum benefit and efficiency for all parties involved in such benchmark or trial exercises. Forecast User's benefits when following the guidelines can be summarized to:

- Performance of a representative trial which will select a FSP that fits their need, specific situation and operational setup
- Short term internal cost savings by running an efficient trial
- Long term cost savings of FSPs, by following the trial standards and thereby help reduce the costs for all involved parties

The guideline provides an overview of the factors that should be addressed when conducting a benchmark or trial and present the key issues that should be considered in the design as well as describe the characteristics of a successful trial/benchmark. We also discuss how to execute an effective benchmark or trial and specify common pitfalls that a Forecast User should try to avoid.

Part 3 of the recommended practices guideline deals with the effective evaluation and verification of variable generation forecasts.

The evaluation of forecasts and forecast solutions is an obligation for any forecast provider as well as end-user of forecasts. It is important, because economically significant, and business relevant decisions are often based on evaluation results. Therefore, it is crucial to design and outline forecast evaluations with this importance in mind, to give this part the required attention and thereby ensure that results are:

1. significant,
2. representative, and
3. relevant.

For example, if forecasts are evaluated against data containing errors, results may still show some significance, but may no longer be considered trustworthy, nor relevant and representative. Additionally, forecast skill and quality has to be understood and designed in the framework of forecast value in order to evaluate the quality of a forecast on the value it creates in the decision processes. This development of the first edition of the recommended practices guideline focused therefore on a number of conceptual processes to introduce a framework for evaluation of wind and solar energy forecasting applications in the power industry. A comprehensive outline of forecast metrics has not been part of this guideline. There are a number of other very useful and comprehensive publications available^{3,4,5} which are specifically referenced in the document. A state-of-the-

Forecast Trial Checklist

--Preparation--

- Determine outcomes / objectives
- Consult expert with trial experience
- Establish timeline and winning criteria
- Decide on live or retrospective trial
- Gather metadata (use IEA checklist spreadsheet)
- Determine if adequately resourced to carry out
- Obtain historical data
- Invite Forecast Service Providers
- Distribute historical and meta-data
- Allow two weeks Q&A prior to trial start
- Begin Trial

--During Trial--

- Develop validation report
- Check interim results
- Provide interim results (if no live data being provided)
- End Trial

--Post Trial--

- Provide final results
- Notify winner(s)
- Contract with winner(s)
- Start Service

Figure 4: The checklist for performing forecasting trials.

³ WWRP/WGNE Joint Working Group on Forecast Verification Research. Berlin, Germany. url: <http://www.cawcr.gov.au/projects/verification/>.

art of forecast evaluation has also not been part of these guidelines, as the process of standardization has only just started in the community. A scientific paper that outlines the choice and selection of evaluation criteria has been prepared by another group as part of work package 2.2 and will be explained below.

1. Impact of forecast accuracy on application

First, it often is difficult to define the forecast accuracy impact to the bottom line as forecasts are just one of many inputs. Second, trials or benchmarks often last longer than anticipated or too short to generate trustworthy results. Thus, the Forecast User is often under pressure to either wrap up the evaluation quickly or to produce meaningful results with too little data. As a consequence, average absolute or squared errors are employed due to their simplicity, even though they seldom reflect the quality and value of a forecast solution for the Forecast User's specific applications.

2. Cost-Loss Relationship of forecasts

A forecast that performs best in one metric is not necessarily the best in terms of other metrics. In other words, there exists no universal best evaluation metric. Using metrics that do not well reflect the relationship between forecast errors and the resulting cost in the Forecast User's application, can lead to misleading conclusions and non-optimal (possibly poor) decisions. Knowing the cost-loss relationship of their applications and to be able to select an appropriate evaluation metric accordingly is important. This becomes especially important as forecasting products are becoming more complex and the interconnection between errors and their associated costs more proportional. Apart from more meaningful evaluation results, knowledge of the cost-loss relationship also helps the forecast service provider to optimize forecasts and develop custom tailored forecast solutions for the intended application.

Lastly, recommendations are made for a number of practical use cases for power industry specific applications.

The scientific work on forecast evaluation has been compiled in a journal article dealing with the selection of evaluation criteria. This article "Evaluation of wind power forecasts – An up-to-date view" submitted in 2019 International Journal of Forecasting lists common and novel evaluation metrics and discusses cost and loss functions and their applicability.

Although forecasts are most often evaluated based on squared or absolute errors, these error measures do not always adequately reflect the loss functions and true expectations of the variety of forecast users today, neither do they provide enough information for the desired evaluation task. A forecast verification framework can actually be very rich, with a wealth of criteria and diagnostic tools, while research in certain areas of forecast verification has intensified over the last decade or so, e.g., for the case of multivariate and probabilistic forecasts. However, the literature on forecast verification is generally very technical and

⁴ Fowler T. Brown B. Lazo J. Haupt S.E. Jensen T. Metrics for evaluation of solar energy forecasts. Tech. rep. NCAR, 2006. url: <http://opensky.ucar.edu/islandora/object/technotes:538>.

⁵ Kariniotakis G. Nielsen HA Nielsen TS. Madsen H. Pinson P. "Standardizing the Performance Evaluation of Short-Term Wind Power Prediction Models". In: Wind Engineering **29.6** (2005), 475~489. doi: 10.1260/030952405776234599.

dedicated to forecast model developers. This makes that forecast users may struggle to select the most appropriate verification tools for their application while not fully appraising the subtleties related to their application and interpretation.

In the work, the most common verification tools were revisited from a forecast user perspective and their suitability for different application examples discussed in conjunction with evaluation setup design and significance of evaluation results.

Finally, a list of freely available data sets was published that are well suited for research and development of wind power forecasting models.

4 Use of Probabilistic Forecasts - Optimal End Use of Forecasts

Work Package 3 targeted the use of probabilistic forecasting.

Uncertainty forecasts are filling a gap of information missing in deterministic approaches and are gradually moving into the control rooms and trading floors. Nevertheless, there are a number of barriers in the industrial adaptation of uncertainty forecasts that have their root in a lack of understanding of the methodologies and their respective applicability. There is a complication level that needs to be overcome in order for industry to move forward.

The Work Package 3 team has been carrying out a survey in 2016 and a number of expert round discussions picking up a number of the loose ends of integration and application issues. The results were published in conference papers and discussed at the WESC conference in Lyngby in June 2017, the Wind Integration Workshop in Vienna in October 2017 and 2018 and the 2017 and 2018 ESIG forecasting workshop in Atlanta, USA and St. Paul, USA.

Additionally a peer reviewed journal publication was submitted and published in autumn 2017 in the Open Access Journal *Energies* (see section 5.1). This was a direct response to the results from the survey, which revealed a significant gap between available products on the market and lack of knowledge and documentation in how to apply, decide and make efficient use of probabilistic forecasts by end-users. The effectiveness of forecasts in reducing the variability management costs of power generation from wind and solar plant is largely dependent upon the ability to effectively choose and use forecast information in the grid management decision-making process. This process is becoming more complex with higher penetration levels and the possibilities to engage large amounts of information to generate forecasts.

In general, it can be stated that the integration of uncertainty forecasts into grid control, grid management and trading strategies is not a fast roll-out into the industry due to the increased level of complexity and computational requirements. Also availability and development of different approaches and methodologies of which some contain limitations have caused distrust to the overall concepts in the past. The paradigm shift required to accept uncertainty as a parameter that needs to be dealt with has been taken up only slowly on requirement lists for system operators and market management companies or traders. It's not that operators and

electrical engineers in general have not been learning to deal with uncertainty before, the N-1 criterion (requirement for a certain amount of available reserves in case of a sudden outage of the largest block of power generation in one's system) is the counterpart of dealing with uncertainty in the grid operation. Nevertheless, dealing with new technologies, where the uncertainty needs to be constantly considered, not only as single events, but also as a whole, is a paradigm shift, where education and new tools are required in the control and trading rooms.

As penetration of wind and solar power increases, this step will naturally be taken due to the increase in uncertainty and grid constraints. Once a threshold of renewables feeding into the grid is reached, probabilistic methods seem to be required in order to manage the large ramps associated with wind changes or strong cloud activity. Societal changes also increase the variability in the load pattern, which needs to be incorporated into the grid management.

Understanding the benefits and the pitfalls when employing probabilistic forecasts requires objective documentation that is scientifically sound, practical and understandable for the industry. For this reason, Work Package 3 is dedicated to translate academic knowledge into industry applications to increase this acceptance and provide objective information about existing methods to deal with uncertainty. This includes the three W's ("what, when and which") regarding methods to be applied to typical or specific challenges and to publish freely accessible objective information for the industry and interested individuals through the website (ieawindforecasting.dk) and open access publications.

The task has set focus on examples of applications in all documentation for the industry in order to demonstrate applicability, benefits and limitations, as well as to enhance the understanding and further development of applications for the industrial use.

4.1 Definitions and Methodologies

One of the gaps of understanding uncertainty in the power industry and among those end-users with an interest in uncertainty forecasts due to higher wind power and solar power penetration levels has been found to be the definition of uncertainty and the corresponding methodologies that provide forecast uncertainty. In the interview analysis from 2016 it was found that many people had difficulties distinguishing some of the main characteristics of uncertainty forecasting:

- (1) forecast error spread
- (2) confidence interval
- (3) forecast uncertainty
- (4) forecast interval

One of the objectives was therefore to define and document these characteristics for the industry.

While the **forecast error spread** is defined as the historically observed deviation of a forecast to its corresponding observation at a specific time, one of the common misunderstandings is that a **confidence interval** is showing the uncertainty of a forecast. This is not the case. By adding and subtracting for example one standard deviation to the

deterministic forecast of wind speed and converting it to wind power, such intervals represent a measure of the deviation to climatology and do not represent current or geographically distributed uncertainty.

The **forecast uncertainty** on the other hand is defined as a possible range of forecast values in the future. In meteorology, this range is defined by the uncertainty of the atmospheric development in the future and represented in ensemble forecasts by applying perturbations to initial and boundary conditions and/or expressing model physics differences.

When represented as **forecast intervals** the so-determined uncertainty band represents forecast uncertainty containing the respective probability of the real value being contained in the range of forecasted values, which will only be observed in the future.

Another important definition that has been documented for the industry by the task are quantiles, which in statistics and the theory of probability, are cut points dividing the range of a probability distribution into continuous intervals with equal probabilities. The 100-quantiles are called percentiles. Forecast intervals can be derived from parametric (e.g. Gaussian distribution) or non-parametric (e.g. empirical distribution functions, kernel density estimation) representations of uncertainty or from a larger number of NWP forecasts in an ensemble forecasting system that represent the forecast uncertainty of the target variable. From these probability density functions (PDFs), quantiles or percentiles can be extracted and higher-order statistics such as skewness and kurtosis can be calculated.

This is where the distinction is most pronounced: from a statistical error measure like standard deviation, it is not possible to derive quantiles or percentiles. Especially in applications like reserve predictions, ramp constraints or optimization tasks for storage applications, this distinction is imperative. Such applications also require that the geographical distribution of the variables is captured by scenarios of ensembles of possible outcomes of a pre-defined value.

In that sense, it has been found important to document these definitions in order to bring a clear and better understanding about which types of uncertainty representation the various methods present and how they are built and should be used to the industrial end-users.

In order to deepen that understanding, the task has been working out a schema of high-level methodologies that are available today as industry standards and explained by their main characteristics in the review article (Bessa et al., 2017) and two conference papers.

The major applications of forecast uncertainty in the power industry are today based on three main methods, processes and procedures and can be summarized to: (see also Figure 5):

- 1) Statistical methods of probabilistic forecasts
- 2) Statistically-based ensemble scenarios
- 3) Physically based ensemble forecasts

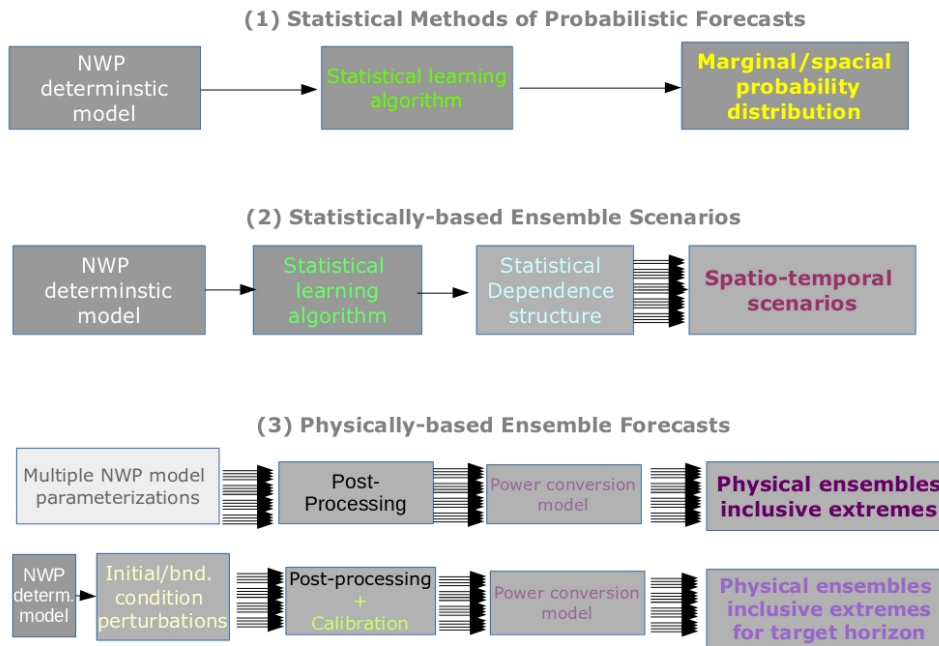


Figure 5: High-level schema of the methods available for uncertainty forecast applications in the power industry.

The first type of methods “**Statistical methods of probabilistic forecasts**” are based on statistical processing of past (historic) data in order to derive a probability density function of the possible forecasting spread. The advantage of such methods are that they are computationally extremely cheap and simple to apply. The disadvantage is that none of these methods produces a realistic representation of the forecast uncertainty in a spatial and temporal manner. There is also no physical dependency on the forward results, as the spread is based on past climatology. Typically, statistical learning algorithms (e.g., neural networks, machine learning) are used to fit historical time series of weather parameters from a NWP model to their corresponding power generation data. From the fitting process, a PDF can be derived and used forward in time.

The second type of methods “**Statistically-based scenarios**” produce statistically-based scenarios that are a result of statistical generation of scenarios from the probability distributions produced by statistical models based on the copula theory. We defined them as scenarios, as the further processing of the approach contains x independent results in contrast to the statistical method, producing one PDF function. Such scenarios are quite similar to the third methods, the physically-based ensembles. The difference and disadvantage of the uncertainty representation from the statistical scenarios is that they only capture the spatial variability of the forecast, but not the temporal variability. We therefore distinguish them here as scenarios rather than ensembles. Outliers that indicate extreme events, for example above cut-out wind speeds of wind turbines require specific analysis, long time series and at least one event in that series to be able to detect the possibility of such an event. The

advantage of the statistically based scenarios is that they are computationally much cheaper than physical ensembles as they are built from a deterministic weather forecast. They also generate a much more realistic uncertainty representation than the pure statistical approach, while only being slightly more computationally costly.

The third type of methodologies, the “**physically based ensembles**” can be considered a post-processing of a set of NWP ensemble members, which are a set of NWP forecasts produced by perturbing the initial or boundary conditions and/or model physics perturbation, the result from different parameterization schemes of one NWP model (“multi-scheme” approach) or complete different NWP models (“multi model” approach), converted in a subsequent phase into power with a curve fitting method. The NWP ensemble is configured to represent the physical uncertainty of the weather ahead of time rather than uncertainty as a function of past experience.

In practice, this means that the NWP ensembles, especially the multi-scheme approach, are event driven, produce outliers and also catch extremes, even those with a return periods of 50 years. This is a clear distinction from statistical methods, because even long time-series of historic data contain too few extreme events to have impact in the learning algorithms.

4.2 Summary and outlook

In summary, WP 3 has been dedicated to fill part of that gap of understanding when probabilistic forecasts and uncertainty information are helpful or required and how to implement or design a forecasting system for that purpose. The WP3 team has been working with a holistic communication strategy both in form of workshops and webinars, also available on the Task’s YouTube channel for re-view or remote view, scientific publications, recommended practices and white papers (see also 5.1).

The conference articles and presentations together with the review article in the Energies journal are now building the basis for the development of a recommended practices guideline for the use and application of probabilistic and uncertainty forecast in phase 2 of the project. The knowledge gained in the first phase will be used to discuss in several workshops with the community where to focus the guideline and to clearly identify the gaps in understanding the applicability of probabilistic forecasts and uncertainty information.

5 Individual Results

5.1 Workshop and Paper on Future Issues for Forecasting Research

One of the first activities of IEA Task 36 was a public workshop in Barcelona (9 June, 2016), where the state of the art and future research issues were discussed. Main ways forward were:

- Nowcast (especially for difficult situations, thunderstorms, small lows, frontal passages, ...)
- Sub 1 hour temporal resolution
- Meteorology below 1km spatial resolution
- Atmospheric stability issues, especially with daily pattern / (Nightly) Low level jets
- Icing
- Farm-Farm interaction, which necessitates a good quality of direction forecast
- Short-term ensembles
- Ramps and other extremes
- Spatio-temporal forecasting
- Rapid Update Models (hourly, with hourly data assimilation)
- Use of probabilistic forecasts and quality of the extreme quantiles
- Do DSOs need different forecasts than TSOs?
- Penalties for bad performance? Incentives for improved performance?
- Seasonal forecasting? What's the business case?
- Data assimilation (with non-linear Kalman filters, 4D Var, ...)

The Science of Making Torque from Wind (TORQUE 2016) IOP Publishing
Journal of Physics: Conference Series 753 (2016) 032042 doi:10.1088/1742-6596/753/3/032042

Wind power forecasting: IEA Wind Task 36 & future research issues

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Abstract. This paper presents the new International Energy Agency Wind Task 36 on Forecasting, and invites to collaborate within the group. Wind power forecasts have been used operatively for over 20 years. Despite this fact, there are still several possibilities to improve the forecasts, both from the weather prediction side and from the usage of the forecasts. The new International Energy Agency (IEA) Task on Forecasting for Wind Energy tries to organise international collaboration, among national meteorological centres with an interest and/or large projects on wind forecast improvements (NOAA, DWD, MetOffice, met.no, DMI, ...), operational forecaster and forecast users.

Figure 6: The paper on future issues for wind power forecasting.

5.2 Mapping of current usage of probabilistic forecasting

Early in the project, we started to map the current knowledge about and actual use of probabilistic forecasts at end users. To this aim, Danish partner WEPROG and French partner MeteoSwift developed a questionnaire, interviewed 24 participants, and analysed the answers. 71% of participants knew something about probabilistic forecasting, but only 21% used any kind of uncertainty information in their operation. Generally, as wind power penetration increased, the interest in probabilistic forecasts also increased. The most common applications were reserve allocation, trading and dispatch, and situational awareness and risk assessment. But the spread between respondents was large.

A separate chapter on Denmark analysed the market structure and participant composition, and found that many of the small CHP plant owners had electricity trading only as a relatively small side business, and were not investing in forecast improvements. Generally, the market had low price volatility at low prices, so the potential incentive for improved forecasts was small for all market participants.

A set of guidelines for the use of probabilistic forecasting concluded the paper. This set of guidelines was then continued in a two separate publications (see the next section).

5.3 Use cases for probabilistic forecasting

The Task wrote two papers about uncertainty forecasting, a somewhat more popular article in IEEE Power and Energy Magazine, and a scientific article of 48 pages in the journal Energies.

Use of Forecast Uncertainties in the Power Sector: State-of-the-Art of Business Practices

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Abstract—The work we present is an investigation on the state-of-the-art use of forecast uncertainties in the business practices of actors in the power systems sector that is part of the “IEA Wind Task 36: Wind Power Forecasting”. The purpose of this task is to get an overview of the current use and application of probabilistic forecasts by actors in the power industry and investigate how they estimate and deal with uncertainties. The authors with expertise in probabilistic forecasting have been gathering information from the industry in order to identify the areas, where progress is needed and where it is difficult to achieve further progress. For this purpose, interview questions were compiled for different branches in the power industry and interviews carried out all around the world in the first six months of 2016. At this stage, we present and discuss results from this first round of interviews and draw preliminary conclusions outlining gaps in current forecasting methodologies and their use in the industry. At the end we provide some recommendations for next steps and further development with the objective to formulate guidelines for the use of uncertainty forecasts in the power market at a later stage.

I. INTRODUCTION

The relevance of forecast uncertainties for wind power and other renewable energies grows as the penetration of these sources in the energy mix increases. Once a certain level of penetration is reached, ignoring the reliability of

roughly goes with wind speed to the power of three, and small errors and uncertainties are thus amplified and have an even higher impact compared to wind speed uncertainties. Weather development associated with fronts moving over large areas where wind is increasing rapidly over a short time are the most critical situations for a balance responsible party or a transmission system operator (TSO): It is under these circumstances that a deterministic forecast may be strongly incorrect and suppress steep ramping that can cause system security issues as well as large imbalances. Translated in the market, it means that there can be a sudden lack of power during a down-ramping event or a too little flexible power that can be down-regulated fast and efficiently, which then results in curtailment. As long as the penetration level of wind is below 20% of generation, such uncertainty can usually be dealt with with a reasonable amount of reserves. As penetration increases, or in the case of island grids or badly interconnected grids, reserves and ancillary services grow above a desirable level.

In order to get an understanding of the current state of use of uncertainty forecasts and to find the gaps in the understanding of uncertainties and the associated forecasting tools and methods, we have been carrying out a study with

Figure 7: The paper on the use of forecast uncertainties in industry.



Figure 8: The paper on how to calculate, and how to deal with uncertainty.

The IEEE paper took its outset in the German EWeLiNE and the US WFIP2 forecasting research projects, and discussed the merits of probabilistic forecasts in various uses. They distinguish between confidence intervals derived from historical accuracy of the forecasts, and a forward looking forecast uncertainty, which takes the weather situation into account, e.g. using an ensemble of meteorological forecasts. It also introduces the metrics used to judge the quality of probabilistic forecasts, and how to assess their value, which has to be problem-specific.

The journal paper “aims at improving this understanding by establishing a common terminology and reviewing the methods to determine, estimate, and communicate the uncertainty in weather and wind power forecasts. This conceptual analysis of the state of the art highlights that: (i) end-users should start to look at the forecast’s properties in order to map different uncertainty representations to specific wind energy-related user requirements; (ii) a multidisciplinary team is required to foster the integration of stochastic methods in the industry sector. A set of recommendations for standardization and improved training of operators are provided along with examples of best practices.” In contrast to the popular article, the journal article also contains formulae and a more thorough explanation of the various metrics, the mathematics behind weather uncertainty forecasts, the history and generation of ensemble forecasts, an exhaustive list of references, and an overview of how to communicate the uncertainty to the user. Use cases from many countries in reserve requirements and unit commitment, participation in electricity markets, predictive grid management, maintenance scheduling of wind power plants and long-term portfolio planning are also discussed in detail. A long list of recommendations concludes the paper.



Review

Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry

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Abstract: Around the world wind energy is starting to become a major energy provider in electricity markets, as well as participating in ancillary services markets to help maintain grid stability. The reliability of system operations and smooth integration of wind energy into electricity markets has been strongly supported by years of improvement in weather and wind power forecasting systems. Deterministic forecasts are still predominant in utility practice although truly optimal decisions and risk hedging are only possible with the adoption of uncertainty forecasts. One of the main barriers for the industrial adoption of uncertainty forecasts is the lack of understanding of its information content (e.g., its physical and statistical modeling) and standardization of uncertainty forecast products, which frequently leads to mistrust towards uncertainty forecasts and their applicability in

5.4 Minute-scale forecasting workshop and paper

In June 2018, a collaborative forecasting workshop with Task 32 “Lidar Technology” has been held at DTU Wind Energy in Risø. The workshop attracted participants both from the Lidar community and the forecasting community where a broad range of discussions around the use of remote sensing instruments, especially lidars for the use of minute-scale forecasting, current use of lidar data and possibilities as well as limitations for the future use of these types of data in wind power forecasting. The workshop identified three applications that need minute-scale forecasts: (1) wind turbine and wind farm control, (2) power grid balancing, (3) energy trading and ancillary services. The main conclusions after the workshop were that there is a need for further investigations into the minute-scale forecasting methods for different use cases, and a cross-disciplinary exchange of different method experts should be established. Additionally, more efforts should be directed towards enhancing quality and reliability of the input measurement data.

A group of 9 people from the workshop worked through the results and discussions of the workshop and wrote a review journal publication that was published in February 2019 in the open-access journal Energies [Würth et al., 2019].

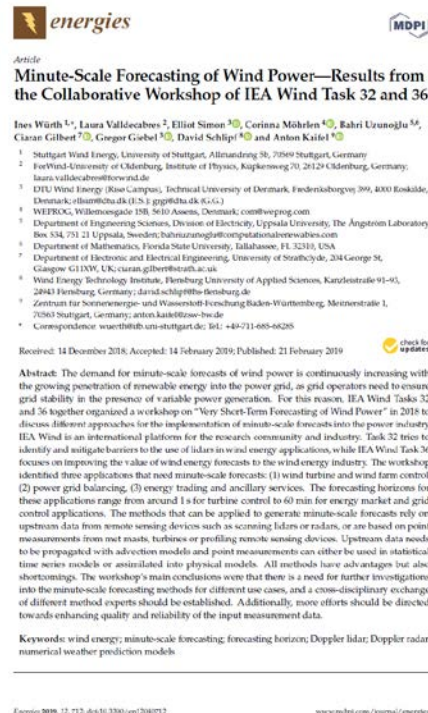


Figure 9: The paper on the results of the common Task 32/36 workshop.

5.5 Dissemination and communication

There were three main dissemination channels. Most importantly, personal communication and talks or posters on conferences added new contacts to the Task mailing list, spread the word about the work performed in the Task, and made the Task well visible within the scientific and business community. As a general rule, an overview poster of the Task was delivered to most conferences where one of the WP leaders team went. Shown to the right is the latest one of phase 1, presented at the WindEurope Summit in Hamburg in September 2018.

Another channel of communication was the website ieawindforecasting.dk. Additional information was a list of publications, a list of partners and a news section.

Finally, the Task [YouTube channel](#) (see below for a screenshot) was used to transmit most



Figure 10: The most recent poster, displayed at the European Wind Summit in Bilbao, April 2019.

meetings live (though non-public) and to keep videos of the workshops in full length available. A series of Webinars throughout November 2018 presented the major results of the Task.

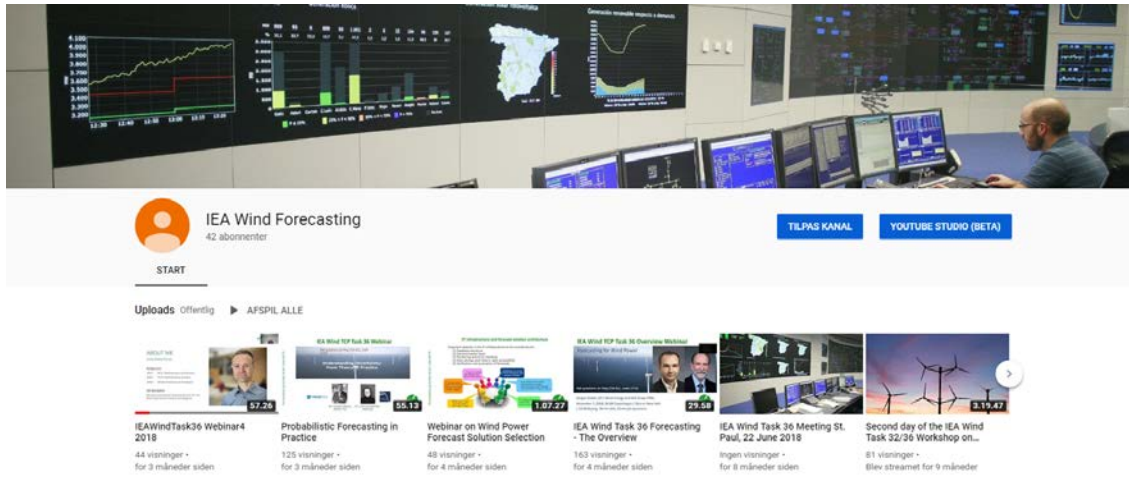


Figure 11: The YouTube channel of IEA Wind Task 36, with the most recent series of webinars.

6 List of publications

See also ieawindforecasting.dk/publications .

Journal Papers

S. E. Haupt, M. Garcia Casado, M. Davidson, J. Dobschinski, P. Du, M. Lange, T. Miller, C. Möhrlen, A. Motley, R. Pestana, J.W. Zack: The Use of Probabilistic Forecasts in Theory and Practice, IEEE Power and Energy Magazine, submitted for Nov.-Dec 2019 volume.

Würth, I.; Valldecabres, L.; Simon, E.; Möhrlen, C.; Uzunoğlu, B.; Gilbert, C.; Giebel, G.; Schlipf, D.; Kaifel, A.: [Minute-Scale Forecasting of Wind Power—Results from the Collaborative Workshop of IEA Wind Task 32 and 36](#). *Energies* **2019**, *12*, 712.

Bessa, R.J.; Möhrlen, C.; Fundel, V.; Siefert, M.; Browell, J.; Haglund El Gaidi, S.; Hodge, B.-M.; Cali, U.; Kariniotakis, G.: [Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry](#). *Energies* **2017**, *10*, 1402, doi:10.3390/en10091402

Online: <http://www.mdpi.com/1996-1073/10/9/1402/pdf>

J. Dobschinski, R. Bessa, P. Du, K. Geisler, S.-E. Haupt, M. Lange, C. Möhrlen, D. Nakafuji, M. d.I.T. Rodriguez: [Uncertainty Forecasting in a Nutshell: Prediction Models Designed to Prevent Significant Errors](#), IEEE Power and Energy Magazine, vol. 15, no. 6, pp. 40-49, Nov.-Dec. 2017. doi: 10.1109/ MPE.2017.2729100.

Conference Publications

C. Möhrle, R. Bessa: [Understanding Uncertainty: the difficult move from a deterministic to a probabilistic world](#). Proc. [17th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant](#), Stockholm, Sweden, October 17.-19, 2018

Corinna Möhrle, John Zack, Jeff Lerner, Aidan Tuohy, Jethro Browell, Jakob W. Messner, Craig Collier, Gregor Giebel: [Recommended Practices for the Implementation of Wind Power Forecasting Solutions Part 2&3: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS AND EVALUATION OF FORECAST SOLUTIONS](#). Proc. [17th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant](#), Stockholm, Sweden, October 17.-19, 2018

Corinna Möhrle: [Recommended Practices for the Implementation of Wind Power Forecasting Solutions Part 1: Forecast Solution Selection Process](#). Proc. [17th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant](#), Stockholm, Sweden, October 17.-19, 2018

G. Giebel, J. Cline, H. Frank, W. Shaw, B-M. Hodge, P. Pinson, J. Messner, G. Kariniotakis, C. Draxl and C. Möhrle: [IEA Wind Task 36 Forecasting for Wind Power](#). Proc. [16th Wind Integration Workshop](#), Berlin (DE), 26-29 June 2017.

C. Möhrle, R. Bessa, J. Jørgensen, G. Giebel: [Uncertainty Forecasting Practices for the Next Generation Power System](#). Proc. [16th Int. Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant](#), Berlin (DE), 26-29 June 2017.

C. Möhrle, C. Collier, J. Zack, J. Lerner: [Can Benchmarks and Trials Help Develop new Operational Tools for Balancing Wind Power?](#) Proc. [16th Int. Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant](#), Berlin (DE), 26-29 June 2017.

G. Giebel, J. Cline, H. Frank, W. Shaw, B-M. Hodge, P. Pinson, J. Messner, G. Kariniotakis, C. Draxl and C. Möhrle: *IEA Wind Task 36 Forecasting*. Proc. [Wind Energy Science Conference](#), Lyngby (DK), 26-29 June 2017.

G. Giebel, J. Cline, H. Frank, W. Shaw, P. Pinson, B-M. Hodge, G. Kariniotakis, J. Madsen, and C. Möhrle (2017) , *IEA Wind Task 36 on Wind Power Forecasting and Future Research Issues*, Proc. [Eighth Conference on Weather, Climate, Water and the New Energy Economy](#), part of the [97th American Meteorological Society General Meeting](#), Seattle (US), 23 - 26 January, 2017

C. Möhrlen, R.J. Bessa, M. Barthod, G. Goretti and M. Siefert: [Use of Forecast Uncertainties in the Power Sector: State of the Art of Business Practices. Proc. 15th Int. Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms](#), Vienna (AT), 15 - 17 November, 2016.

Please note: the Task overview poster (Figure 10) has been shown on several conferences and is not mentioned separately here, it has its own page on <https://www.ieawindforecasting.dk/Publications/Posters-og-Handouts>.

Recommended Practices

IEA Recommended Practice on Forecast Solution Selection

The Recommended Practice is composed of three parts:

Part 1: Forecast Solution Selection Process

Part 2: Design and Execution of Benchmarks and Trials

Part 3: Evaluation of Forecasts and Forecast Solutions

The documents can be accessed online here: <http://ieawindforecasting.dk/news>.

Appendix A

Handouts on several of the major results of IEA Wind Task 36:

- Project overview
- IEA Recommended Practice for Selecting Renewable Power Forecasting Solutions
- Understanding uncertainty: The difficult move from a deterministic to a probabilistic world

More are currently being prepared and will be on the ieawindforecasting.dk homepage.

IEA Wind Task 36 Forecasting for Wind Power



FORECASTING FOR YOU

Setup

Wind power forecasts have been used operatively for over 25 years. Despite this fact, there are still several possibilities to improve the forecasts, both from the weather prediction side and from the usage of the forecasts.

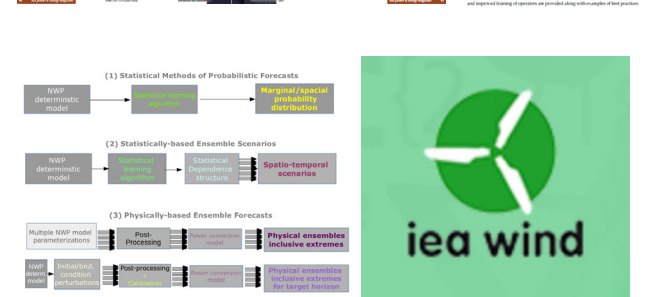
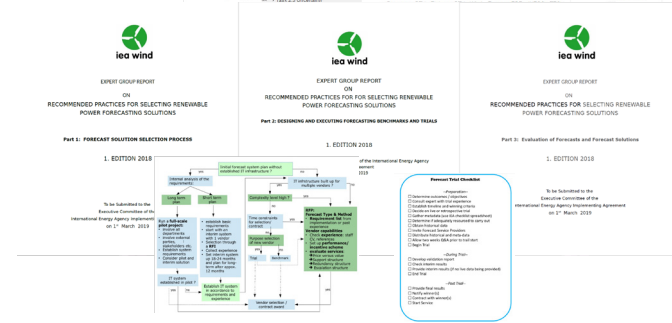
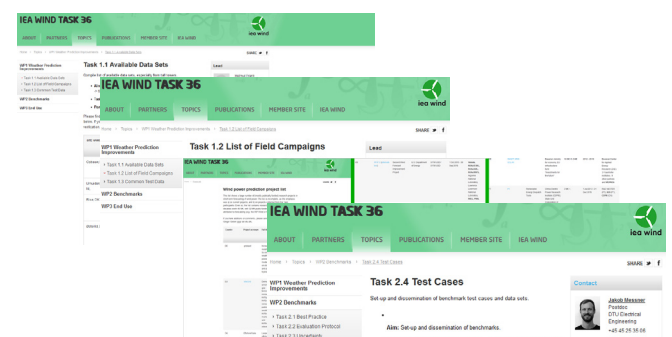
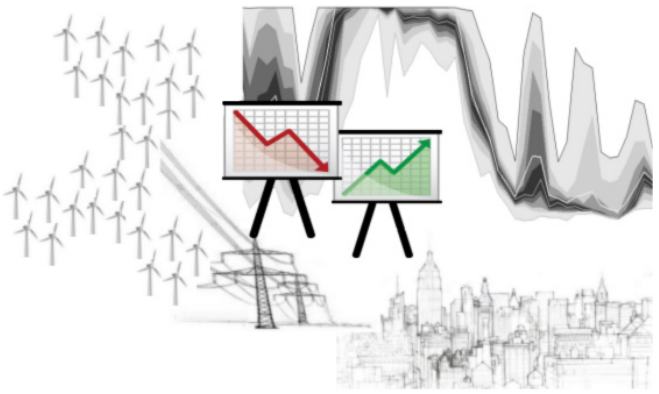
The IEA Wind Task is divided in three work packages: Firstly, a collaboration on the improvement of the scientific basis for the **wind predictions** themselves. This includes numerical weather prediction model physics, but also widely distributed information on accessible datasets. Secondly, we deal with the **conversion to power** and issues affecting the forecast vendors. Thirdly, we will be engaging end users aiming at dissemination of the best practice in the usage of wind power predictions. The Task is currently in its second phase, 2019-2021.

Results of phase I (2016-2018)

We developed an **information portal**, with links to data, projects and knowledge useful for wind power forecasting. This could be a list of tall masts useful for online validation of NWP models, a list of field campaigns with open data for model verification, or a selection of benchmarks for forecasts with established data sources and existing reference frameworks.

A major result was the IEA Wind Recommended Practice (RP) on **Forecast Solution Selection**, detailing out the necessary steps to get the best adapted forecasts for the individual use case. The RP starts with the initial deliberations which might or might not end up with the decision to do a forecast trial. The second document shows how to conduct such a trial in order to yield acceptable and usable results for both the end user and the participating vendor. The last part shows how to evaluate the trial to get 1) significant, 2) representative and 3) reliable results.

For **probabilistic forecasts**, we published two papers with an overview (for a broader readership) and one with a long list of specific use cases (more technically oriented). We also classified methods for uncertainty forecasting, and tried to establish a common vocabulary. We also mapped the current use of probabilistic forecasts through a questionnaire.

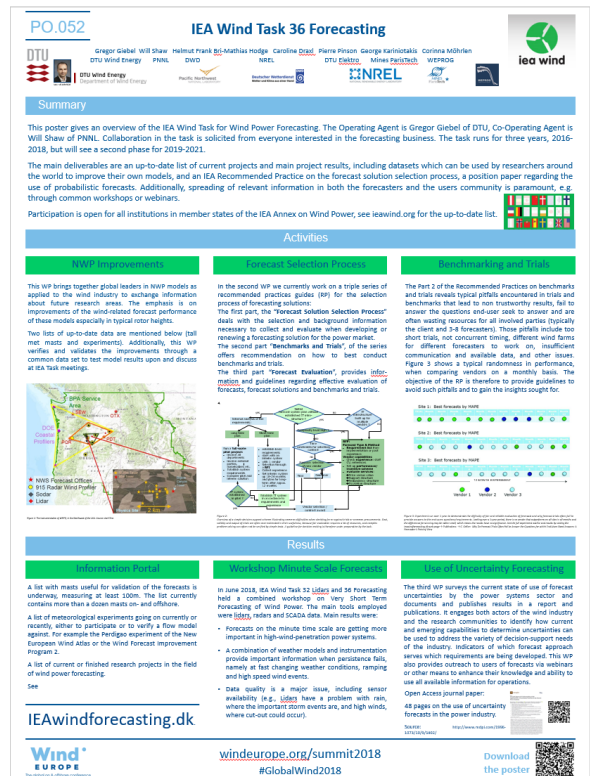


Impact

The Task sends out **news** a few times a year, is present on conferences and meetings, and has its own **YouTube** channel. There, alongside video transmissions of the public workshops, we also had 4 **webinars** of half an hour talks plus audience questions on the major results of phase I. The fourth one was an additional one on forecast use in Denmark.

The Task members also try to get a enhance **collaboration** between weather prediction providers and vendors, and between vendors and end users. One activity for the current phase of the Task (2019-2021) is a look into **standardization** of data, to make data exchange more fluent across the industry. Another activity is to estimate the **value** of better forecasting.

We also collaborate with other Wind Tasks, e.g. in the common workshop on minute scale forecasting we had together with Task 32 **Lidar**. In the future, we will also collaborate with IEA PV Task 16 **Solar** resource, which also deals with forecasting and has some of the same issues.

PO.052 IEA Wind Task 36 Forecasting

Summary

This poster gives an overview of the IEA Wind Task for Wind Power Forecasting. The Operating Agent is Gregor Giebel of DTU. Co-Operating Agent is Will Shaw of PNNL. Collaboration in the task is solicited from everyone interested in the forecasting business. The task runs for three years, 2016-2018, but will see a second phase for 2019-2021.

The main deliverables are an up-to-date list of current projects and main project results, including datasets which can be used by researchers around the world to improve their own models, and an IEA Recommended Practice on the forecast solution selection process, a position paper regarding the use of probabilistic forecasts. Additionally, spreading of relevant information in both the forecasters and the users community is paramount, e.g. through common workshops or webinars.

Participation is open for all institutions in member states of the IEA Annex on Wind Power, see ieawind.org for the up-to-date list.

Activities

- NWP Improvements:** This WP brings together global leaders in NWP models as applied to the wind industry to exchange information about future research areas. The emphasis is on improvements of the wind-related forecast performance of these models especially in typical error regimes. Two lists of up-to-date data are mentioned below (all met. mast and experiments). Additionally, this WP verifies and validates the improvements through a common data set to test model results upon and discuss at task meetings.
- Forecast Selection Process:** In the second WP we currently work on a triple series of recommended practices guide (RP) for the selection process of forecasting solutions. The first part, the "Forecast Solution Selection Process" deals with the selection and background information necessary to collect and evaluate when developing or renewing a forecasting solution for the power market. The second part "Benchmarks and Trials" of the series offers recommendation on how to best conduct benchmarks and trials. The third part "Forecast Evaluation" provides information and guidelines regarding effective evaluation of forecasts, forecast solutions and benchmarks and trials.
- Beta Forecasting and Trials:** The Part 2 of the Recommended Practices on benchmarks and trials reveals typical pitfalls encountered in trials and benchmarks that lead to non-transparent results, fail to answer the questions end-user seek to answer and are often wasting resources for all involved parties. Typically the client and 3-4 forecasters. These pitfalls include too short trials, not concurrent testing, different wind farms for different forecasters to work on, insufficient communication and available data, and other issues. Figure 3 shows a typical randomness in performance, when comparing vendors on a monthly basis. The objective of the RP is therefore to provide guidelines to avoid such pitfalls and to gain the insights sought for.

Results

- Information Portal:** A list with mast useful for validation of the forecasts is underway, measuring at least 200m. The list currently contains more than a dozen masts on- and offshore.
- Workshop Minute Scale Forecasting:** In June 2018, IEA Wind Task 32 Lidar and 36 Forecasting held a combined workshop on Very Short Term Forecasting of Wind Power. The main tasks employed were Lidar, reflow and SCADA data. Main results were:
 - A list of meteorological experiments going on currently or recently, either to participate or to verify a flow model against. For example the Herdigeo experiment of the new European wind atlas or the wind forecast improvement program 2.
 - A list of current or finished research projects in the field of wind power forecasting.
- Use of Uncertainty Forecasting:** The third WP surveys the current state of use of forecast uncertainty by the power systems sector and documents and publishes results in a report and publications. It engages both sectors of the wind industry and the research communities to identify how current and emerging capabilities to determine uncertainties can be used to address the variety of decision support needs of the industry. Indicators of which forecast approach serves which requirements are being developed. This also provides outreach to users of forecasts via webinars or other means to enhance their knowledge and ability to use all available information for operations. Open access journal paper: 46 pages on the use of uncertainty forecasts in the power industry.

IEAWindforecasting.dk

Wind EUROPE

windurope.org/summit2018
#GlobalWind2018

Download the poster

Collaboration



Currently, some 250 people from 12 countries are collaborating on forecasts. There are meetings every half year, often in conjunction with relevant conferences. We also have special sessions at conferences for outreach, and usually an overview poster. If you are **interested** to collaborate, or just to be informed about new results, please contact Gregor Giebel.



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The **International Energy Agency** is an autonomous organisation which works to ensure reliable, affordable and clean energy for its 30 member countries and beyond.

The **IEA Wind Technology Collaboration Programme** supports the work of 38 independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues.

IEA Wind Task 36 connects 250 experts from academia, forecast vendors and end users to improve the accuracy and value of wind power forecasts.



IEA Wind Task 36 Forecasting for Wind Power



RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

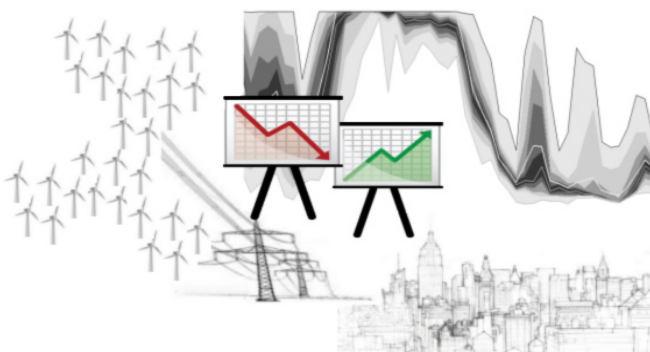
Challenge

The effectiveness of forecasts in reducing the variability management costs of power generation from wind and solar plants is dependent upon both the accuracy of the forecasts and the ability to effectively use the forecast information in the user's decision-making process. Therefore, there is considerable motivation for stakeholders to try to obtain the most effective forecast information as input to their respective decision tools.

One of the main challenges today is that the industry does not have any standards regarding the design, development and implementation of forecast solutions and forecast evaluation. This lack of standardised procedures and requirements is an unhealthy development, considering the importance and necessity of integrating higher amounts of renewable energies on a global basis.

Solution

To overcome some of the obstacles and barriers in the integration of forecasting solutions, the IEA Wind Task 36 has established a guidance to stakeholders on the three main parts of this decision process. The first part "**Forecast Solution Selection Process**" deals with the selection and background information necessary to collect and evaluate when developing or renewing a forecasting solution for the power market. The second part "**Benchmarks and Trials**" deals with how to set up and run benchmarks and trials in order to test or evaluate different forecasting solutions against each other and the fit-for-purpose. The third part "**Forecast Evaluation**", provides information and guidelines regarding effective evaluation of forecasts, forecast solutions as well as benchmarks and trials.



Forecast Solution Selection

While every forecasting solution contains very individual processes and practices, there are a number of areas that all forecasting solutions have in common. Figure 1 shows a typical high-level forecast solution framework. For any industry it is important to establish standards and standardized practices in order to streamline processes, but also to ensure security of supply with a healthy competition structure. The Recommended Practice guideline is providing state-of-the-art practices that have been carefully collected by expert forecasters and forecast users, and have been reviewed by professionals and experts in an appropriate number of countries with significant experience in wind energy forecasting.

The key element of the IEA Recommended Practice is to provide basic elements of decision support and thereby encourage forecast users to **analyze their own situation** and use this analysis to design and request forecasting solutions that fits their own purpose rather than applying a doing what-everybody-else-is-doing-strategy. It is highly recommended to **engage with the forecast vendors** in order to discuss the vendors recommendations. It is often most beneficial for all parties to issue a request for information, conduct vendor meetings and explain the goal and objective of a solution and let the forecasters give their recommendations.

The guideline provides therefore not only aspects for the selection process to forecast users, but also for vendors new to the market or those wanting to evolve to a new level of service and support as a guideline to state of the art practices that are recommended to be incorporated into business practices. Figure 2 is the decision support tool that has been developed as an aid to develop procedures and processes inside the organisation with stakeholder engagement. It is explained in detail in the guideline.

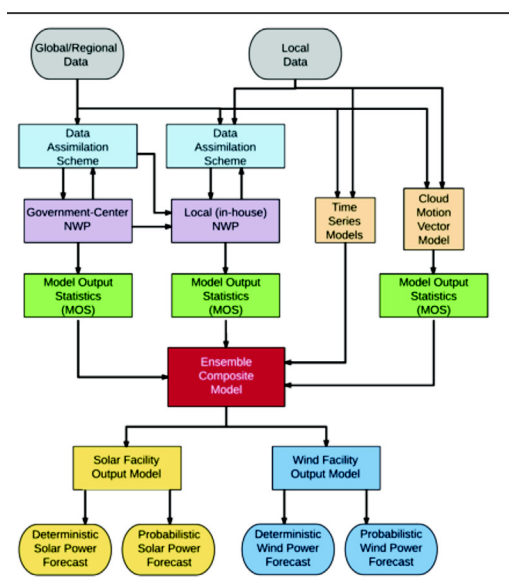


Figure 1: High-level overview of the components and data flow of a typical state-of-the-art forecasting solution.



Forecast Evaluation

The evaluation of forecasts and forecast solutions is an obligation for any forecast provider as well as end-user of forecasts. It is important, because economically significant and business relevant decisions are often based on evaluation results. Therefore, it is crucial to design and outline forecast evaluations with this importance in mind, give this part the required attention and thereby ensure that results are:

- **significant,**
- **representative and**
- **relevant.**

How to setup an evaluation process and achieve these principles has been the core of the developed recommended practices guideline. These three main principles are outlined in the guideline and brought into perspective with the general concept of evaluation uncertainty and uncertainty of measurement data collection and reporting, which is one of the base principles of evaluation and verification tasks. Here, the impact and consequences of errors in measurement data collection and reporting is explained.



Figure 4 : Conceptualized framework for forecast evaluation.

Furthermore, metrics for evaluation and verification have been conceptualized and categorized in order to provide an issue oriented guideline for the selection of metrics in an evaluation framework (see Fig. 4).

The concept of developing an **evaluation framework** is described and practical information on how to maximize value of operational forecasts, how to evaluate benchmarks and trials and new forecasting techniques or developments is provided.

Lastly, recommendations are made for a number of practical use cases for power industry specific applications.

Where to get the guideline

The recommended practice guidelines are available as open access on ieawindforecasting.dk.

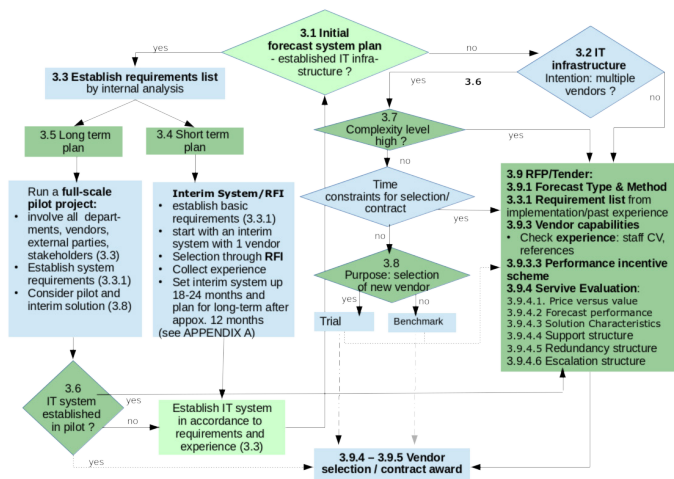


Figure 2: The decision support flow chart for the initial deliberations of the forecast solution selection.

Benchmarks and Trials

When selecting a forecast solution, benchmark and trial exercises can consume a lot of time both for the entity conducting it (the "Forecast User") and the participating Forecast Service Providers (FSPs). These guidelines and best practices are based on years of industry experience and intended to achieve maximum benefit and efficiency for all parties involved in such benchmark or trial exercises.

Forecast Users **benefit** in these areas when following this advice:

- Performance of a representative trial which will select a FSP that fits their need, specific situation and operational setup
- Short term internal cost savings by running an efficient trial
- Long term cost savings of FSPs, by following the trial standards and thereby help reduce the costs for all involved parties

The guideline provides an overview of the factors that should be addressed when conducting a benchmark or trial and present the key issues that should be considered in the design as well as describe the characteristics of a successful trial or benchmark. We also discuss how to execute an effective benchmark or trial and specify common **pitfalls** that a forecast user should try to avoid.

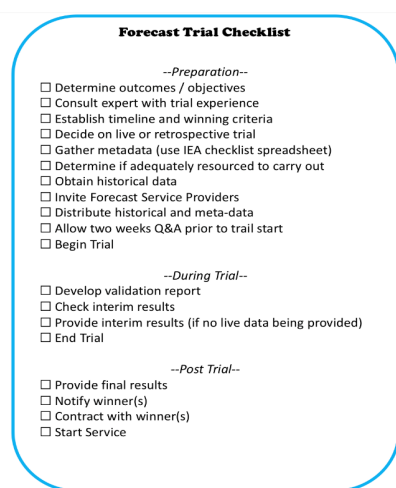


Figure 3: The checklist for performing forecasting trials.

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IEA Wind Task 36 connects 250 experts from academia, forecast vendors and end users to improve the accuracy and value of wind power forecasts.



IEA Wind Task 36

Forecasting for Wind Power



Understanding Uncertainty: the difficult move from a deterministic to a probabilistic world

Challenge

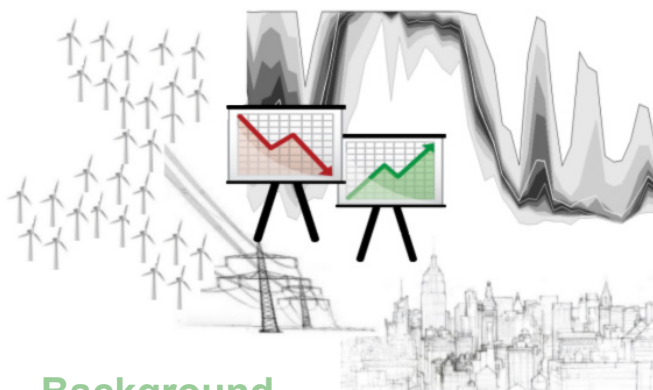
Uncertainty forecasts are filling a gap of information missing in deterministic approaches and are gradually moving into the control rooms and trading floors. Nevertheless, there are a number of barriers in the industrial adaptation of uncertainty forecasts that have their root in a lack of understanding of the methodologies and their respective applicability.

There is a complication level that needs to be overcome in order for industry to move forward. The effectiveness of forecasts in reducing the variability management costs of power generation from wind and solar plant is largely dependent upon the ability to effectively choose and use forecast information in the grid management decision-making process. This process is becoming more complex with higher penetration levels and the possibilities to engage large amounts of information to generate forecasts.

Solution

The Work Package 3 team of the IEA Wind Task 36 has picked up a number of the loose ends of integration and application issues, discussed them in a various conferences, and published recommendations and use cases in a number of conference papers. All publications and a number of workshops and webinars are available through the Tasks webpage.

A peer reviewed publication was published in the Open Access Journal Energies (see reference section). This was a direct response to the results from a survey carried out in 2016, which revealed a significant gap between available products on the market and lack of knowledge how to apply, decide and make efficient use of probabilistic forecasts by end-users.



Background

Understanding the benefits and the pitfalls when employing probabilistic forecasts requires **objective documentation** that is scientifically sound, practical and understandable for power engineers as well as scientists and managers.

For this reason, the IEA task 36 is dedicated to translate academic knowledge into understanding how industry applications have to be setup and how to increase the acceptance of uncertainty information in the forecasting processes by providing objective information about existing methods and how to deal with uncertainty. This includes the three W's ("what, when and which") regarding methods to be applied to typical or specific challenges and to publish freely accessible objective information for the industry and interested individuals through the website (ieawindforecasting.dk) and open access publications.

In summary, the IEA Wind Task 36 is dedicated to fill part of that gap of understanding when probabilistic forecasts and uncertainty information are helpful or required and how to implement or design a forecasting system for that purpose. The Task has set focus on examples of applications in all documentation for the industry in order to demonstrate the applicability, benefits and limitations, as well as to enhance the understanding and further development of applications for industrial use.



Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry

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Abstract: Around the world the usage of wind energy is starting to become a major energy provider in electricity markets, as well as the production of multiple services markets in both consumer and producer markets. The volatility of supply and demand and the increasing penetration of wind energy into the electricity markets has led to the need for improved forecasting methods and tools to manage the variability of supply and demand. This paper presents a survey of the current state of the art in wind power forecasting, with a focus on the challenges and opportunities associated with the use of probabilistic forecasting methods. The paper reviews the current state of the art in wind power forecasting, with a focus on the challenges and opportunities associated with the use of probabilistic forecasting methods. The paper reviews the current state of the art in wind power forecasting, with a focus on the challenges and opportunities associated with the use of probabilistic forecasting methods.

Definitions and Methods

IEA Wind Task 36 has compiled several definitions of uncertainty and the corresponding methodologies that provide forecast uncertainty. The main characteristics of uncertainty forecasting are:

- 1) forecast error spread
- 2) confidence interval
- 3) forecast uncertainty
- 4) forecast interval

While the **forecast error spread** is defined as the historically observed deviation of a forecast to its corresponding observation at a specific time, one of the common misunderstandings is that a **confidence interval** is showing the uncertainty of a forecast. This is not the case. By adding and subtracting for example one standard deviation to the deterministic forecast of wind speed and converting it to wind power, such intervals represent a measure of the deviation to climatology and do not represent current or geographically distributed uncertainty.

The **forecast uncertainty** on the other hand is defined as a possible range of forecast values in the future. In meteorology this range is defined by the uncertainty of the atmospheric development in the future and represented in ensemble forecasts by applying perturbations to initial and boundary conditions and/or expressing model physics differences.

When represented as **forecast intervals** the so-determined uncertainty band represents forecast uncertainty containing the respective probability of the real value being contained in the range of forecasted values, which will only be observed in the future.

The major applications of forecast uncertainty in the power industry are today based on three main methods, processes and procedures and can be summarized to: (see also figure on right side):

- 1) Statistical methods of probabilistic forecasts
- 2) Statistically-based ensemble scenarios
- 3) Physically based ensemble forecasts

The first type of methods, “**Statistical methods of probabilistic forecasts**”, are based on statistical processing of past (historic) data in order to derive a probability density function of the possible forecasting spread. The advantage of such methods are that they are computationally extremely cheap and simple to apply. The disadvantage is that there is no physical dependency on the forward results, the spread is based on past climatology. Typically, statistical learning algorithms (e.g., neural networks, machine learning) are used to fit historical time series of weather parameters from a NWP model to their corresponding power generation data. From the fitting process, a PDF can be derived and used forward in time.

The second type of methods, “**Statistically-based scenarios**”, produce scenarios, i.e. possible futures, that are a result of statistical generation from the probability distributions produced by statistical models based on the copula theory. The difference and disadvantage of the statistical scenarios is that they only capture the spatial variability of the forecast, but not the temporal variability. Outliers that indicate extreme events require specific analysis, long time series and at least one event in that series to be able to detect the possibility of such an event.

The third type of methodologies, the “**physically based ensembles**” are a set of NWP forecasts produced by perturbing the initial or boundary conditions (e.g. with “Breeding”, “Singular vector”, “Kalman Filters”) and/or model physics perturbation, the result from different parameterization schemes of one NWP model (“multi-scheme” approach) or complete different NWP models (“multi model” approach), converted in a subsequent phase into power with a curve fitting method. The NWP ensemble is configured to represent the physical uncertainty of the weather ahead of time rather than uncertainty as a function of past experience.

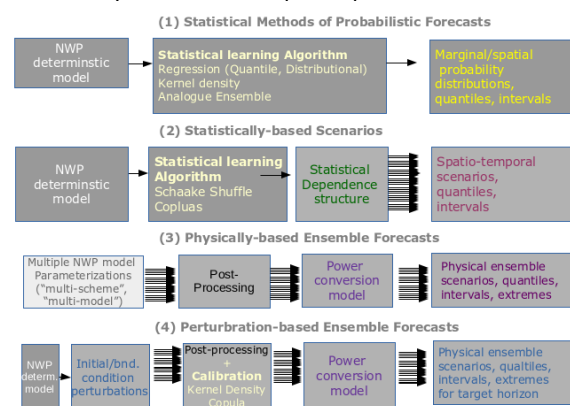


Figure: Schemata of the different methodologies to generate uncertainty forecasts for the power industry.

Further reading

Open access publications on ieawindforecasting.dk

S. E. Haupt, M. Garcia Casado, M. Davidson, J. Dobschinski, P. Du, M. Lange, T. Miller, C. Möhrlen, A. Motley, R. Pestana, J.W. Zack: The Use of Probabilistic Forecasts in Theory and Practice, IEEE Power and Energy Magazine, submitted for Nov.-Dec 2019 volume.

Würth, I.; Valldecabres, L.; Simon, E.; Möhrlen, C.; Uzunoğlu, B.; Gilbert, C.; Giebel, G.; Schlipf, D.; Kaifel, A.: Minute-Scale Forecasting of Wind Power—Results from the Collaborative Forecasting of IEA Wind Task 32 and 36. *Energies* 2019, *12*, 712. Open Access: <https://www.mdpi.com/1996-1073/12/4/712>

Bessa, R.J.; Möhrlen, C.; Fundel, V.; Siefert, M.; Browell, J.; Haglund El Gaidi, S.; Hodge, B.-M.; Cali, U.; Kariniotakis, G.: Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry. *Energies* 2017, *10*, 1402, doi:10.3390/en10091402. Open Access: <http://www.mdpi.com/1996-1073/10/9/1402/pdf>

J. Dobschinski, R. Bessa, P. Du, K. Geisler, S.-E. Haupt, M. Lange, C. Möhrlen, D. Nakafuji, M. d.I.T. Rodriguez: Uncertainty Forecasting in a Nutshell: Prediction Models Designed to Prevent Significant Errors, IEEE Power and Energy Magazine, vol. 15, no. 6, pp. 40-49, Nov.-Dec. 2017. doi: 10.1109/MPE.2017.2729100.

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