IEA Wind Task 36: The New Phase for the Wind Power Forecasting Task

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***Abstract*—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 International Energy Agency (IEA) Task on Wind Power Forecasting organises international collaboration, among national weather centres, forecast vendors and forecast users. The Task looks back on the first 3 years, and just started the second three-year period. Collaboration is open to IEA Wind member states, 12 countries are already therein.**

The 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 and a benchmark. Secondly, we try to improve the derived power forecasts and deal with forecast vendor related matters to bring the entire industry forward. Thirdly, we will be engaging end users aiming at dissemination of the best practice in the usage of wind power predictions.

The main result of the first phase is the IEA Recommended Practice for Selecting Renewable Power Forecasting Solutions. This document in three parts (forecast solution selection process, designing and executing forecasting benchmarks and trials and evaluation of forecasts and forecast solutions) takes its outset from the recurrent problem of forecast users of how to choose a forecast solution. The first report describes how to tackle the general situation, while the second report specifically describes how to set up a forecasting trial so that the result is what the client intended. Many of the pitfalls we have seen over the years, are avoided. Other results of the first phase include a comprehensive review paper on the use of uncertainty forecasts in the power industry and an information portal related to forecasting.

In the second phase of the Task, we will take up additional topics such as the uncertainty propagation through the modelling chain, the use of distributed measurements for forecasting, and some initial standardisation of data flows and formats.

Keywords—wind power forecast, wind power prediction, IEA, forecast selection, probabilistic forecast

I. Introduction

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.

During the three years Phase I of Task 36 (2016-2018), academia, meteorological institutes, forecast vendors and end users worked together to improve both the quality of the forecasts and the use of the forecast information. In this effort, we developed a Recommended Practice on how to select a forecasting solution, either as a new solution or as an additional/replacement solution. This paper is heavily inspired by the final report of Phase I, and the description of work of Phase II.

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 speed and direction. However, for wind power prediction applications NWP improvements should ideally 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 ensemble forecasts, initial conditions, the model physics, or boundary conditions of limited area models 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 three work packages (WP) 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 the meteorological aspects of the forecasts. WP2 focused on the conversion of meteorological variables to power output, the benchmarking of forecast performance as well as the interaction between forecast vendors and users in the selection of the best forecast solution for a specific application. WP3 addressed the use of probabilistic forecasts and optimal end use of forecasts.

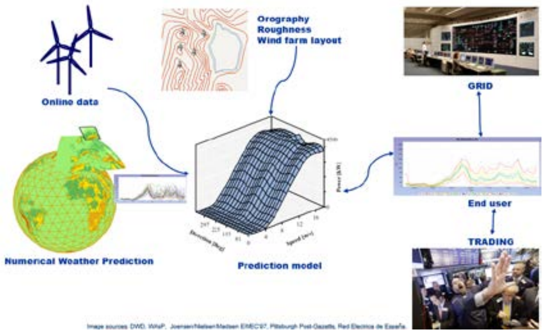

Fig. 1. The flow of data through a wind power prediction system. The local information (center top) is only used occasionally.

II. 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. These needs were addressed in WP 1 by:

- Compiling a list of available sources of real-time data, especially from tall towers;
- Reporting annually on field measurement programs that could support NWP validation; and
- Organizing 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 [1] 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, the application of numerical methods and data assimilation techniques 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 WP1, 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 several 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.

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

The main outcome of WP2 was the publication of an IEA Recommended Practices for Selecting Renewable Power Forecasting Solutions (see Figure 2) subsequently referred to as "RP". The document is split into three 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 renewable energy forecasting solution. 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 and forecast solutions as well as benchmarks and trials.

The work is coordinated to provide an industry recommended practice version for practical usage in relation to the implementation of forecasting solutions

While every forecasting solution contains 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 RP contains state-of-the-art procedures 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 renewable energy forecasting.

Fig. 3. Title pages of the RP documents: (left) forecast solution selection process, (middle) designing and executing forecasting benchmarks and trials, and (right) evaluation of forecasts and forecast solution.

Part 1 of the RP provides 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 fit their own purpose rather than applying a "what-everybody-else-is-doing" strategy. In order to facilitate this process, a decision support tool was developed to guide forecast users in the design and implementation of a forecast solution selection

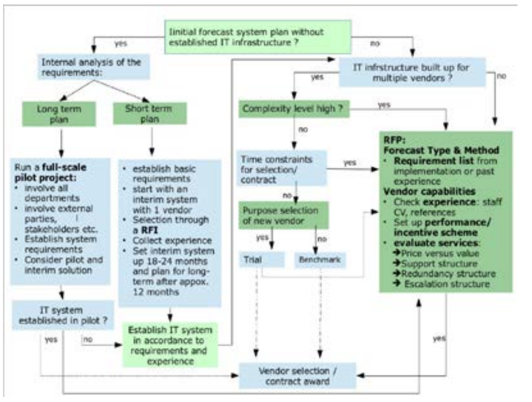

Fig. 2. A flow chart that summarizes a decision support tool for the design and implementation of a forecast solution selection process.

process. An overview of this tool is schematically depicted in Figure 2. 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 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.

Part 2 of the RP addresses the design and execution of forecasting benchmarks and trials. 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 as:

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

The guideline provides an overview of the factors that should be addressed when conducting a benchmark or trial (see Figure 4 for an example) and presents the key issues that should be considered in the design and describes 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.

Part 3 of the RP 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,

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 trail 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

Fig. 4. The checklist for performing forecasting trials.

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. Therefore, the development of the first edition of the RP guidelines focused on a number of conceptual processes to introduce a framework for the 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 [1],[2],[3], which are specifically referenced in the document. A state-of-the-art standard for 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 WP2 and will be explained below.

1. Impact of Accuracy Assessment Methods on an Application

It often is difficult to define the forecast accuracy impact to an application's bottom line as forecasts are just one of many inputs. Second, trials or benchmarks often last longer than anticipated or are 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 become 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 FSP provider to optimize forecasts and develop custom tailored forecast solutions for the intended application.

Recommendations are made in Part 3 for a number of practical use cases for specific power industry 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 [4] 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 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.

IV. Use of Probabilistic Forecasts - Optimal End Use of Forecasts

WP 3 targeted the use of probabilistic forecasting, which provide a Forecast User with an estimate of the uncertainty of a forecast as well as predictions of the future value of target variable of interest (e.g. wind power production). Uncertainty forecasts fill a gap of information 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 WP 3 team performed a survey in 2016 and a number of expert round discussions that addressed 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 Workshops in Berlin, Germany and Stockholm, Sweden in October 2017 and 2018 and the 2017 and 2018 ESIG forecasting workshops 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 [6]. 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, derive decisions and make efficient use of probabilistic forecasts by end-users. The effectiveness of forecasts in reducing the management costs of the power generation variability from wind and solar plants 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 has not been 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 previously dealt with uncertainty. For example, 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 cloud-induced solar variations. Societal changes also increase the variability in the load patterns, which also needs to be incorporated into the grid management process.

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, WP3 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 Task 36 website (ieawindforecasting.dk) and open access publications.

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 information. In the interview analysis from 2016 it was found that many people had difficulties distinguishing among 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. This definition was described in a paper for last year’s Wind Integration Workshop [7].

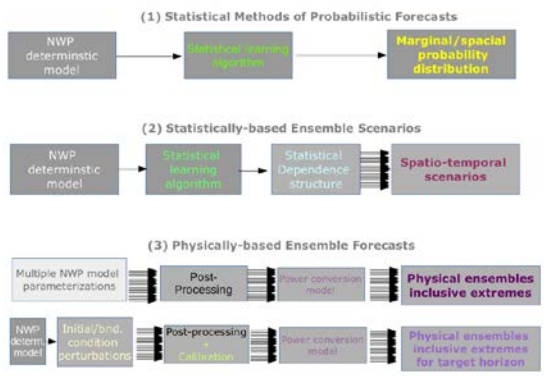

Fig. 5. High-level schema of the methods available for the production of forecast uncertainty infprmation in the power industry. [7]

In order to deepen that understanding, WP3 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 [6] 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 are summarized in Fig. 5 (see [7] for the explanation):

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

V. OTHER RESULTS

Additional results from Task 36 were the results of two workshops, a first one on research gaps in short-term prediction leading to a paper [8], and the second one together with the IEA Wind Task 32 on Lidars discussing the state of the art in minute scale forecasting [9]. Additionally, we communicated the major results in the form of webinars on the IEA Wind Forecasting YouTube channel [10].

VI. PHASE II

The second phase of the Task adds some new targets in addition to a continuation of work on most of the Phase 1 topics:

A. *Discussion of possible parts of the forecasting processes to be standardised in the future*

For the forecast vendors and end users alike, a common data format and possibly an open-source reference implementation would streamline the process of both, conducting trials and changing the forecast vendor. This would increase the competition between forecasters, but also lower the effort on both sides. Therefore, we will analyse current data transfer standards like the IEC 61850 series on SCADA communication and their wind power brethren, 61400-25, but also look to IEA Windbench and other de-facto standards.

As a second activity, Task members will collaborate with the standardisation effort in the International Electrotechnical Commission (IEC) Subcommittee SC8A in the writing of a Technical Report on Renewable Energy Power Forecasting Technology (IEC TR 63043) and related material.

B. *Online verification and benchmarking of current NWP models with met mast data*

Recently, a number of dedicated datasets from meteorological campaigns became available for model improvement, especially in the US Wind Forecast Improvement Project in Complex Terrain (WFIP2). We aim at defining and running a benchmark for meteorological models for wind power forecasting. We will use a formal Validation and Verification (V&V) framework, which is already used in the US Atmosphere2Electrons research programme. For more details, please refer to the Task homepage.

C. *Detailed review of uncertainty propagation through the modeling chain.*

The preparation of wind power forecasts chains several models in a sequence to get to the final outcome. This subtask will perform a literature overview and attempt a full Uncertainty Quantification through all the submodels of the modelling chain, from the numerical weather prediction inputs and the data uncertainties to the probabilistic forecasts. The aim is a position paper.

D. *Assessment of the value of probabilistic forecasts*

An important driver for improving forecast methodologies is the added value for the forecast user. The value for different stakeholders (TSO, DSO, balance responsible or the producer) will depend on the specific market design. A subtask of this WP will therefore focus on evaluating the value of forecast, and the options for added value by using probabilistic forecasts in different market setups. The value will be assessed by developing a market and forecast simulation, with input from realised and forecasted wind generation and market prices. The platform will give quantitative insights on the value created for different stakeholders with more accurate forecasting and application in day-ahead and balancing markets. Additional applications in e.g. ancillary service markets will be assessed qualitatively. A possible dissemination of the results might be a game, which would use actual use cases and data to provide insights into the use of probabilistic forecasts.

E. *Development of an IEA Recommended Practice for the requirements of data and instrumentation for real-time forecasting.*

State of the art wind power forecasting methodologies utilise, besides wind speeds from weather forecasts, onsite real-time power measurements from SCADA systems and meteorological measurements from met masts or alternatives thereof to compute wind power. The combined use of the trend of the forecast and measured meteorological variables is the state-of-the-art method to be able to predict wind power in the next few hours, as well as high speed shut-down and critical ramping events. This explains the need for high quality measurements, even though similar considerations are applicable in the management of dispatch, i.e. ranging down to cover also lower wind speeds. Today, there are no standards or guidelines on the quality requirements for instrumentation or on the type of instrumentation itself that would help system operators to develop their grid codes. The IEC 61400-12 standard, guidelines from MEASNET and some recommended practices from IEA Wind Tasks are applicable only in resource assessments. The US environmental protection agency (EPA) provides a "Meteorological Monitoring Guidance for Regulatory modelling Applications", which is a guideline on the collection of meteorological data for use in regulatory modelling applications such as air quality. All these guidelines and standards provide recommendations for instrument, measurement and reporting for all main meteorological variables. However, only the EPA guidelines deal with real-time usage, but only for meteorological modelling. These guidelines and practices need to be studied and adjusted for the real-time usage in the power industry and specific guidelines or recommended practices developed for the real-time environment.

VII. Conclusions

IEA Wind Task 36 is the largest collaboration for wind power forecasting, connecting 300+ people from weather prediction, forecast vendors, end users and academia. The Task helps to discuss common interests, improve the methods, and aids the value creation at end users. For collaboration, please contact the Operating Agent (grgi@dtu.dk).

Acknowledgment

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