International Energy Agency (IEA)
Implementing Agreement for Co-operation in the Research and Development of Wind Energy Systems (IEA Wind)

Task Proposal
Forecasting for the Weather Driven Energy System

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1 Scope

The framework conditions have changed significantly since 2016, when IEA Wind Task 36 Forecasting for Wind Energy started. Already then, most of the vendors used their knowledge to provide both wind and solar power forecasts, as many of their clients had both technologies in their portfolio. The just released IPCC report on the physical science basis [1] makes it very clear that humans are the main contributor to the rapid climate change we experience in recent years. One of the solutions to prevent if not climate change itself, but at least the more drastic variants, is to steer society to a carbon free course, which with current technology means a many-fold increase in renewable generation. Since the generation is variable with the “fuel”, i.e., wind and solar radiation, the entire system has to be flexible to adapt to these changes. Therefore, a new Task is proposed under the heading of **Forecasting for the Weather Driven Energy System**. Energy system in this respect means not only the power system, i.e. electricity, but also sector coupling and storage. This will entail stronger collaboration with especially IEA PVPS Task 16 on the solar resource, which also is responsible for forecasting, but also with tasks in other IEA TCPs like hydropower, hydrogen, or biomass, all of which have indicated their interest.

The proposed Task under the *IEA Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems* (IEA Wind) focuses on **improving the value of renewable energy forecasts**.
There are three distinct areas of challenge in forecasting wind power. The first is in the continuing effort to improve the representation of physical processes in weather forecast models through both new high performance initializations and tailored parameterizations. The second area is the heterogeneity of the forecasters and end users, the full understanding of the uncertainties throughout the modelling chain and the incorporation of novel data into power forecasting algorithms. A third area is representation, communication, and use of these uncertainties to industry in forms that readily support decision-making in plant operations and electricity markets. This Task will facilitate coordination of efforts in all three of these areas and will work to define best practices for model evaluation and uncertainty communication.

The new Task will collaborate with several other Tasks. In 2018, Task 36 had a common meeting with Task 32 Lidars, looking into minute scale forecasts [2], and we will continue that collaboration. The work on the value of forecasts should be coordinated with Task 26 Cost of Wind, and we will investigate common themes with Task 25 Integration. For very short time scales, the use of a lidar (Task 32) could be beneficial for wind farm flow control (Task 44) or hybrid power plants (Task 50). A new field is forecasting for airborne wind energy (Task 48). At the same time, we agreed on a collaboration with IEA PVPS Task 16 on High Penetration of PV, as well as IEA Hydro Annex IX Valuing Hydropower Services, the IEA Hydrogen TCP and IEA Bioenergy Task 44 Flexible Bioenergy and System Integration, as forecasting for all renewables share significant commonalities in approach and impact.

The work packages are largely connected to the stakeholders in the process working on it. WP1 is mainly for meteorologists, WP2 for power forecasters from academia and forecast vendors, and WP3 collects the view of the end users. The improvement of the representation of underlying physics is recognized by the IEA as being a long-term challenge, and the first work stream will focus on accelerating progress by enhancing communication and coordination among international groups working in this area. The second work stream will focus on coordinating, and standardizing where possible, the various approaches to establishing and expressing errors and uncertainties for wind and power forecasts for both physical and statistical models. It will also include the provision of benchmarks and, in conjunction with DoE-run labs in the US, aim to make the excellent Solar Forecast Arbiter to a tool also useable for wind forecasts. The third work package will engage both research and the wind related industry to develop recommendations for representations of probabilistic forecast information that are most useful for the operational environment. It will further shed light on how to use probabilistic forecasts in wind energy, and what the value of improved forecasts and forecast use can be.

The expected outcomes of this Task are increased efficiency of international research efforts to improve wind and power forecasting together with publications documenting best practices for assessing forecast model performance, the quantification and representation of uncertainties, and the communication and use of probabilistic information to industry.

2 Introduction

Forecasting the chaotic behavior of the atmosphere for wind, cloud cover, aerosols and precipitation remains a primary challenge of the atmospheric sciences. Because atmospheric motions occur on scales ranging from 1 mm to 10^4 km (10 orders of magnitude), and even if the physics was completely known would need an initial state from the entire atmosphere, it is not feasible to explicitly forecast the evolution of the atmosphere at all scales at once. Consequently, prognostic numerical models generally resolve a range of scales encompassing the phenomena of interest, and the smaller scales are parameterized. For mesoscale atmospheric models, which are not only used for general weather forecasts but also to provide short-term wind forecasts, parameterizations are used to represent processes occurring on horizontal scales less than the 1–10 km grid spacing explicitly resolved by the models. These parameterizations reflect assumptions about which physical processes are dominant on the unresolved scales and generally have constants that may be adjusted according to observations. To create a forecast, a model must be initialized with observations, and the combination of observation errors, initialization error and the highly non-linear governing equations of the models leads to additional error in the forecasts.

General challenges to modeling for wind resource characterization, including wind forecasting, have been described in numerous venues. A workshop in Seattle found those two research gaps:

- Lack of full understanding of flow physics, including effects of stability and heterogeneous or topographically severe land surfaces, and intermittent mixing processes
- Insufficient data for validation or verification

There are several recent and planned field studies that are intended to fill some of the data gaps and thus assist in improving the physics of wind forecast models. In the U.S., the Wind Forecast Improvement Project 1 (WFIP 1) [3] used enhanced observation networks to evaluate the impact of improved initializations on wind and power forecasts over a full annual cycle. A second WFIP started in early 2015 using enhanced networks of instrumentation to validate and improve the underlying physics of wind forecast models in complex terrain [4]. The New European Wind Atlas (NEWA) project [5] ran from 2015 to 2019 to develop a mesoscale to microscale model-chain validated with large field experiments in various terrain and wind climate conditions. The improvements in

One of the conclusions of the “Forecasting Techniques” TEM [6] was that, while forecasting is a critical component of large-scale integration of wind energy into the grid, it does not have full value unless accompanied by information describing the uncertainties in the forecast. There are a

variety of techniques for creating forecasts with associated uncertainties. These include generating ensembles of forecast model runs, uncertainty quantification using analog ensembles, purely statistical approaches, and various combinations of statistical and deterministic approaches. Determining the uncertainty associated with renewable power forecasting is rather more involved than for wind (or solar) forecasts, since the conversion process from wind to power introduces additional uncertainties. Therefore, wind power forecast models typically require not only the input from numerical weather prediction (NWP) models, but also local meteorological observations and supervisory control and data acquisition (SCADA) data.
The TEM report also noted that probabilistic information greatly increases the value of a forecast for risk management, generator scheduling, and dispatch and electrical markets.

For both wind and power forecasts, there is general agreement that knowing the uncertainties is important. At the same time, there is no general understanding of what to do with the information or in what form it would be most useful. There is currently a spectrum of forecast uncertainty information that can be provided, ranging from simple means and standard deviations through additional statistical moments such as skewness or kurtosis, through quantile information and up to full distributions and scenarios. During the first phase we wrote a paper showing many use cases for probabilistic forecasts [9]. In Phase II, we wrote a review paper on the propagation of uncertainty throughout the modelling chain [10].

During Phase III, there now exists an open-source validation tool that can be used for assessing wind power deterministic and probabilistic forecast performance in a standard way using standard means of exchanging power and weather data consistent with the Phase II recommended practice. The U.S. Department of Energy Solar Forecast Arbiter (SFA) [11] has now been applied to live industry forecast trials for evaluating commercially available solar forecasts. The power forecast validation component is applicable to wind power forecasting with minor changes. SFA is also used as an online database for storing publicly available datasets (e.g, the SURFRAD radiations network) which can then be used in validation of wind or solar power forecasts.

The value of forecasting in liberalized electricity markets can be a major contributor to the financial success of an operating renewable energy power plant. Sadly, the marketing of wind (or solar) energy during the operating lifetime of the renewable energy power plant usually is not a consideration in the pre-operational due diligence engineering reports that are used for obtaining financing of the project. These reports focus on the most likely or poorest performing annual energy production years of a power plant so that lenders can assess the financial risk. Only in the last decade though have renewable power plant developers or offtakers began to consider energy forecasting in the financial viability of an operating renewable energy power plant before a long term power purchase agreement is signed. One of the main reasons for this oversight is that independent engineering consultants that perform these resource assessment analyses usually do not have the expertise on the market-specific forecast energy imbalance penalty or tariff schemes.

Renewable power forecasting and the quality of the underlying weather forecast models can impact the revenue stream from power generation sales. But the accuracy of weather models is by no means the only factor and arguably a much smaller factor than the impact of the electricity market energy imbalance tariffs. How the energy imbalance calculation is defined affects the impact that power forecasting errors have on the expected power marketing revenues. For this reason, it’s vital to communicate the relative importance of electricity market rules in the context of forecast accuracy. There will always be some level of forecasting error associated with a variable generation forecast dependent on the weather. However, electric energy market rules are often devised without knowledge of state-of-the-art forecast error levels. So we see, for example, arbitrary error threshold targets defined that ultimately affect the annual revenues of a power plant on the order of 1-5% of total revenue. However, market rules can be shaped to minimize the impact of this uncertainty.

3 Objectives and Expected Results

This Task will focus on facilitating communication and collaborations among international research groups engaged in the improvement of the accuracy and applicability of forecast models and their utility for the stakeholders in the wind industry, in the power sector and in the energy system. This Task has the following specific objectives:

- To establish an active, open forum for sharing knowledge among the participants, related IEA Wind Tasks and other related TCPs through workshops, dissemination and communication measures
- To establish and communicate standards and frameworks for the operation and evaluation of forecast model performance
- To identify paths to increased application and utility of forecast information to the task stakeholders
- To advance the knowledge in the underlying atmospheric physics, in the mathematical models converting the transforming atmospheric quantities to energy system application variables, in the modelling of the uncertainty and in the applications and decision making
- To identify most promising areas for new research to improve the quality and utility of forecasts
- To provide guidelines for the implementation of optimal forecasting solutions

It is anticipated that outcomes from this Task could include

- Increased international collaboration and transfer of knowledge regarding improvement of forecast models for the wind, power and energy industry
- A generally accepted framework for the implementation, operation and evaluation of forecast models and solutions
- Guidelines for the calculation and evaluation of uncertainties in forecast models
- Guidelines for the requirements of instrumentation and measurement data for forecasting models and solutions
- Development of a general framework for the quantitative use of forecast uncertainties by the wind, power and energy industry
- Special sessions in conferences and four dedicated workshops
- Webinars and other outreach to inform the industry of advances in forecasting methods, performance and applications

4 Approach and Methodologies

The activities for this IEA Task are divided among three topical work packages (WPs) organised by stakeholder groups, for simplicity's sake meteorologists (WP1), forecast vendors (WP2) and

end users (WP3). Academics are involved in all three topical WPs. Additionally, Management of the Task is in its own work package (WP0). The four WPs are synergistic and will be executed simultaneously. All four WPs run throughout the whole Task period (M1-M48).
Since many activities and work areas span across multiple WPs, Work Streams (WSs) are defined as cross-cutting activities. The individual WPs are therefore mainly administrative units, while the topical work is going on in the work streams. Each WP has some WS it is responsible for, plus some collaboration in other streams that touch the area. Where applicable, the work to be done is detailed out in the individual WPs under the WS description.

4.1 Cross-Cutting Work Streams

Below, the work streams are anchored in the WP that has most relevance. This yields a matrix structure like the following (M7 means month 7 of the Task):

Table 1: Work streams

WS:	**WP1 Weather**	**WP2 Power**	**WP3 Applications**	**Deliverable**	**#, Due**	**Collabo-ration**
Atmospheric physics and modelling (WP1)	★			List of experiments and data	D1.1, Ongoing	WMO, PVPS T16
Airborne Wind Energy Systems (WP1)	★			Presenta-tions on workshops	Part of D2.1	Task 48 Airborne Wind Energy
Seasonal forecasting (WP1)	★			Workshop / Paper	D1.6 / M19	Hydro TCP, Hydrogen TCP, Biomass TCP
State of the Art for energy system forecasting (WP2)		★		Workshop / Paper RecPract on Forecast Solution Selection v3	D2.1 / M7, M12 M2.1 / M36	T25, PVPS Task 16, Hydro TCP, Hydrogen TCP, WMO, …
Forecasting for underserved areas (WP2)		★		Public dataset	D2.4 / M24	WMO
Minute scale forecasting (WP2)		★		Workshop / Paper	D2.5 / M31, M36	Wind Tasks 32 Lidar, 44 Farm Flow Control and 50 Hybrids

Uncertainty / probabilistic forecasting (WP3)				Uncertainty propagation paper with data RecPract	D 2.6 / M42 M48	PVPS T16
Decision making under uncertainty (WP3)				Training course Games	M12 M18	
Extreme power system events (WP3)				Workshop	D3.6 / M42	ESIG, IEA ISGAN, PVPS T16, G-PST
Data science and artificial intelligence (WP3)				Report	D2.3 / M30	
Privacy, data markets and sharing (WP3)				Workshop / Paper Data format standard	D3.5 / M15	ESIG IEEE WG Energy Forecasting
Value of forecasting (WP3)				Paper	D 3.4 / M33	
Forecasting in the design phase (WP3)						Task 50 (hybrids), PV T16, hydrogen TCP

Atmospheric physics and modelling
Knowing the atmosphere and its developments is the basis for forecasting for all horizons beyond a few hours. Especially with the new emphasis on seasonal forecasting and forecasts for storage management, the weather forecasts are in focus. This work stream spans mostly WP1, where the larger meteorological centres are at home, but crosses over into WP2, where the derived application variables need knowledge of the meteorology.

Airborne Wind Energy Systems
IEA Wind Task 48 works with novel devices getting wind energy from previously unseen heights (3-600m above ground). At the moment, these devices are mostly in the research stage, but initial discussions on the forecastability and the wind in those heights will take place on the Task meetings and the State-of-the-Art and Research Gaps workshop (D2.1).

Seasonal forecasting
Seasonal forecasts are growing in importance for the power grid planning, especially, where hydropower, storage and other technologies are involved. This topic is also interlinked to the uncertainty forecasting work stream and will focus on the communication between weather and energy community. Seasonal forecasts are a subset of weather forecasting, and are therefore managed by WP1. WP3 will interlink these communities and serve as a platform to establish new applications for the use of seasonal forecasting in the energy community and the transformation into a carbon free energy system.

State of the Art for energy system forecasting
In year 1, the new Task will organise a workshop on the state of the art and future research issues in energy forecasting, inviting other TCPs (PVPS Task 16 already has voiced interest). The workshop is modelled after the first workshop in Task 36, which established a baseline and research agenda. The established state-of-the art will be carried forward in the recommended practice guideline for forecasting solution selection and its dissemination to the industry at workshops, webinars, conferences, white papers and a book publications. While every WP contributes to this activity, the conversion to application variables such as power is central here, therefore this WS will be managed by WP2.
Forecasting for underserved areas
Forecasting in the established markets like Europe, North America or China has both a long tradition, and a well-established infrastructure. But in sync with the wind industry opening up new markets for the technology, the grid operators and/or market participants need good solutions to deal with the novel influx of power. However, both data availability and possibly market or grid code structures might be quite different in those places. The quality of the forecast needs to be provided by the vendors, which is why this WS is run by WP2. The recommended practices for the implementation of renewable energy forecasting solutions will also serve the under-served markets as valuable guidelines. An adaptation considering the limitations of under-served or emerging countries will be one focus area in collaboration with WP1.
Minute scale forecasting
On the power plant level, forecasts some minutes ahead can be used for battery control in hybrid power plants, in wind farm flow control (it takes minutes for the wind field to pass through a larger wind farm), and sometimes also in market structures like the Australian market, which operates on a 5-min schedule. Advances in minute-scale forecasting have been investigated in phase 2 and will be further developed and communicated to the industry. Since minute scale forecasting mainly uses data driven tools (statistical or machine learning), the WS is administered by WP2, but has connections to WP1 for knowing the wind flow through a farm, and to WP3 with regards to usage of the forecasts. We plan to have a workshop together with the IEA Wind Tasks on Lidar and on Hybrid Power Plants, and possibly others.
Uncertainty / probabilistic forecasting & decision making under uncertainty
Uncertainty is inherent in the forecasting of weather driven power generation. The preparation of calibrated uncertainty measures is done by the WP2 stakeholders. In WP3, the integration of forecast uncertainty into power grid management, wind power bidding strategies, and storage operation, will be analysed considering the role of humans (and their perception of uncertainty and risk), costs and benefits of end-users. Since this is the research topic needing more attention, WP3 is responsible for this WS. Analysis of critical bottlenecks in forecasting accuracy, as well as validation and value determination, are topics that will be dealt with in interdisciplinary groups and collaborations with associated partners and other WPs. Additionally, a qualitative overview paper of the propagation of uncertainty through the modelling chain was submitted in mid-2021. A natural extension of the work is to use the techniques on real data, to calculate the results and to publish it as a new paper.
Extreme power system events
Weather extremes are a threat to the power system, not only due to destruction of hardware, but also due to inadequate unit commitment, grid planning and available generation units. The challenges are broad and reach into the power markets, where extreme prices can be caused by extreme weather events. Knowledge and exchange of information on how to forecast extremes and mitigate effects from such extremes are topics that need attention in the next phase. While there is a strong weather dependency in this WS, the work will be structured according to the needs of the end users, and therefore administered by WP3.

Data science and artificial intelligence
Data-driven decision-making under risk and uncertainty is being augmented with advances in data science (e.g., deep learning with heterogenous data sources) and artificial intelligence (e.g., reinforcement learning for optimization) techniques. WP3 will administer the WS and will collect success cases of application in the forecasting and decision-making domain of wind power forecasting, and study different paradigms for integrating uncertainty, data science and AI, such as: human-in-the-loop decision making, digital twins for decision support, interactive machine learning, etc. Finally, trust and security of data-driven methods will be a topic of analysis, in particularly considering industry requirements for integrating new technologies in their business processes. For meteorologists, the numerical weather prediction models change faster than the climate. How can the local adaption or some kind of AI adapt to this without running a new and old model in parallel for a long time? To shorten this parallel time would free up some effort to be used somewhere else.
Forecasting Data & Data Policies
Forecast data and policies are in constant movement and change due to the transformation of our energy system into a carbon free future. WP3 will be collecting information and communicating new developments to the industry and forecasting community to ensure alignment with these developments.
Privacy, data markets and sharing
The transformation of the energy system towards a carbon free generation, and the EU strategy for Common European data spaces that will ensure that more data becomes available for use in the economy and society, requires new policies for data sharing (monetary and non-monetary incentives) and privacy, but also developments of regulatory frameworks and data market designs. This will cover different use cases, such as forecasting and operation & maintenance of wind power plants, where data sharing across the energy value chain can bring benefits for multiple stakeholders (e.g., improved predictability, reduced O&M costs, improvement of turbine component reliability, etc.). The Task also develops its own API, to become a common open-source framework, standardised across vendors, and looks into other data transfer issues.
Value of forecasting
Without value for the end users, there wouldn't be a market for forecasts. The incremental value of increase accuracy is though much harder to assess. The value proposition is though quite country and market specific. Therefore, we will analyse different market structures w.r.t. to the regulatory framework, the amount of renewable power in the system (i.e. whether it is a price taker or price maker), the possibilities for gaming and the implications of gaming for the system.
Forecasting in the design phase
An assessment of the expected forecasting accuracy for a given site was already investigated for a single case. However, since then it has been quiet. The new Task will analyse the tradeoffs between normal siting of the turbines, and the forecast capability type.

While **Climate Modelling** is not explicitly mentioned as a work stream since forecasts for several years ahead can only give indications of deviations from the climate normal on a yearly basis, more interesting for resource assessment, the methods used are quite similar to other types of forecasting, and our group will therefore have a direct connection to the climate modelling community.

4.2 Work Packages

WP 0: Management, coordination and dissemination (Lead: Gregor Giebel/DTU)

A Task web site will be maintained that will provide current information regarding this Task, provide a calendar of meetings and other significant activities, host downloadable documents produced under this Task, and provide links and contact information for key datasets. The smooth operation of the Task (meetings, mailing list, etc.) is also part of this WP. The meetings will often be in conjunction with relevant conferences, where we will try to organize a special session. The Task will also aim at disseminating the knowledge in form of webinars. Where possible or applicable, the workshops will be streamed to e.g., the IEA Wind Forecasting YouTube channel.

Deliverables:
- D 0.1: Website (Ongoing)
- D 0.2: Organization of meetings and special sessions at international conferences on wind energy (M6-M48)
- D 0.3: Webinars to inform users about major Task outcomes (M24-M36)

Milestones:
- M 0.1 – 0.4: Annual reports (M12, M24, M36, M48)
- M 0.5 – 0.12: Organization of two meetings per year (M1, M7, M13, M19, M25, M31, M37, M43)

WP 1: Weather Prediction (Lead: Helmut Frank/DWD, Caroline Draxl/NREL)

Numerical weather prediction is the basis for forecasting fluctuating renewable energy resources as well as variations in demand. This WP brings together experts from meteorological services, research institutes, and private forecast providers to push improvements of NWP models with special relevance for renewable energy i.e., winds in the planetary boundary layer (PBL) beyond the surface layer at typical rotor heights of 50 to 200 m above ground. The usage of various data types, such as data from drones, masts, lidars, sodars and turbines shall be promoted. First, for verification and validation of model forecasts, but also in data assimilation for NWP. The model physics shall be improved to better simulate the effects of changing atmospheric stability, complex terrain, the marine atmospheric boundary layer, air-sea interaction, or specific phenomena such as low-level jets. Especially with the strong development of off-shore wind parks, the question arises how and when to include the effect of these parks on the atmosphere in NWP models. For solar or hydropower forecasting, a similar effort shall be made with the relevant variables, in conjunction with the relevant TCPs and Tasks.

We plan on also connecting with the new IEA Wind Task 48 on Airborne Wind Energy, as model physics improvement will benefit multiple layers of the atmosphere, including higher heights that are targeted for airborne devices.

In ensemble forecasting, current systems are often over-confident and techniques to span the full range of uncertainty must be improved. Relevant forecast time horizons range from less than an hour to a few days. But, ranges of 2 weeks and seasonal forecasting are also important, e.g., for the combination with hydro power or storage systems, or forecasting extreme wind conditions (e.g., hurricanes) and communication thereof.

Machine-learning for wind forecasting is widely applied and will also be an important topic for this WP.
This WP primarily facilitates communication and efficient application of resources in the global wind forecast community. An annual summary describes field measurement campaigns that collect data suitable for model validation, testing data assimilation techniques and model

physics. Both the existence of various data sets and their conditions of access will be documented. This will also serve as one path to alert investigators to opportunities for participation in these studies. This Task might lead to increased data sharing, hopefully also with industry-owned data.

Associated work streams:

- Atmospheric physics and modeling.
- Seasonal Forecasting.

Deliverables:

- D 1.1: Online summary of major field studies supportive of wind forecast improvement; list of available data (ongoing)
- D 1.2: Report on benchmark exercise carried out in Phase II of IEA Wind Task 36 that illustrates the application of V&V (M12)
- D 1.3: Report on forecast horizons and the use of post-processing tools including AI (M24)
- D 1.4: Convene meetings with forecast centers to start the discussion of including energy metrics in NWP model upgrades. (Ongoing)
- D 1.5: Convene workshop and develop paper on seasonal forecasting, emphasizing hydro and storage (M19)

WP 2: Conversion to Application-specific Variables (Lead: John Zack/UL Renewables and Jethro Browell/University of Glasgow)

This second work package will focus on the assessment and improvement of the quantitative links (models) between atmospheric quantities such as wind speed, solar radiation and temperature and application-specific variables (often the power forecast) that are used in the management of integrated energy systems and their individual components. A major objective will be to provide guidance to energy system forecast users about (1) the methods and approaches that are considered to be "state-of-the-art" for individual application-specific variables, (2) the data from energy system components (generators, system operators etc.) that is needed to optimize forecast performance of application-specific variables, (3) the expected accuracy performance levels for critical application variables and the key factors that impact (i.e. cause variability in) the state-of-the-art performance, (4) the expected levels of forecast uncertainty and uncertainty variability for key application-specific variables and the factors that modulate the uncertainty variability and (5) the available datasets, software and online platforms that can be used to test the relative performance of a user-developed or user-selected forecast solution.

The effort will have an integrated energy system perspective and examine the forecasting of application specific variables related to the wind power generation, solar power generation, electric energy demand and optimal management of energy storage systems. A wide range of forecast time horizons will also be considered and range from the minutes ahead to season-ahead time scales. The specific issues that will be addressed will include:

- Assessment of the overall state-of-the-art performance and forecast methods

- Assessment of the state-of-the-art tools and ability to estimate forecast uncertainty and uncertainty variability
- Impact of the availability of data from energy system sources on forecast performance
- Assessment of state-of-the-art methods and performance levels for minutes-ahead forecasting
- Assessment of state-of-the-art methods and performance levels for month-ahead to seasons-ahead forecasting
- Assessment of state-of-the-art methods and performance levels for multi-time-scale prediction of key application variables for extreme power system events
- Identification of the key problem and solution attributes to determine which data science/AI tools/approaches will provide the maximum benefit for the forecasting energy-application-specific variables
- Compilation of an inventory of datasets, software and online platforms that can assist users in the selection of optimal forecast solutions for their application variables with a focus on users in underserved areas (i.e. outside of Europe and North America)
- Integration of the above information into a third version of the IEA Recommended Practice for Forecast Solution Selection.

Associated work streams:
- State of the art for energy system forecasting
- Forecasting for underserved areas
- Minute scale forecasting

Deliverables:
- D 2.1: Workshop and paper on state-of-the-art and future research issues in the forecasting of weather-dependent energy system variables (M7, M12)
- D 2.2: Workshops, reports and conference papers on methods and performance levels for key under-optimized forecasting applications. (Ongoing)
- D 2.3: Report and conference papers on techniques to optimize the use of data science/AI tools for the forecasting of energy-application variables (M30)
- D 2.4: Inventory and web interface of data and tools for forecasting applications in underserved areas. (M24)
- D 2.5: Workshop and paper on minute-scale forecasting for hybrid power plants or wind farm control, in conjunction with Task 32 on Lidars, Task 44 on Farm Flow Control and Task 50 on Hybrid Power Plants (M31, M36)
- D 2.6: Journal paper on uncertainty propagation through the modelling chain, based on real data (M42)

Milestones:
- M 2.1: Version 3 of IEA Recommended Practice on Forecast Solution Selection (M36)

WP 3: Applications (Lead: Corinna Möhrlen/WEPROG, George Kariniotakis or Simon Camal/ParisTech + Ricardo Bessa/INESC TEC)

The third work package will investigate the state-of-the-art forecasting applications for the challenges towards a carbon free energy system and focus on the translation and transformation from academic knowledge and developments into industry applications. WP3 will bundle and provide assistance to the industry in how to implement forecasting to serve the needs of industry and to ensure that the value of forecasting is understood and reflected in the selection of forecasting tools and their validation. By providing objective information from an international community, it is possible to support the energy and electric transformation ahead of us. This also includes the emerging or under-served countries, where e.g. weather forecasting is sparse and the development limited by the restricted forecasting possibilities.

Overall, WP3 will serve as a link from developments towards industry applications and their communication and discussion with the research community, stakeholders and end-users of forecasting applications and solutions. WP3 spans over almost all work streams and will enhance the already established collaborations with the IEA PVPS Task 16 and IEA Wind Task 32 to also include Hydro TCP, Hydrogen TCP and Biomass TCP. The ongoing work and milestones along will also be discussed at relevant workshops and conferences such as Wind Integration Workshops, ESIG forecasting workshops, ICEM, WESC and EMS and AMS Energy Meteorology annual meetings. The involvement in each of the work streams is briefly described below.

Associated work streams:

- Uncertainty / probabilistic forecasting & decision making under uncertainty
- Extreme power system events
- Data science and artificial intelligence
- Forecasting Data & Data Policies
- Privacy, data markets and sharing
- Value of forecasting
- Forecasting in the design phase

Deliverables:

- D 3.1: Continued development of practical industry guidelines and application examples that can be used in Recommended Practices guidelines or standardization documents
- D 3.2: Continued work on Recommended Practice for data and instrumentation requirements for real-time forecasting (in collaboration with IEA Wind Task 32 and IEA PVPS Task 16)
- D 3.3: Communication and documentation of the use of probabilistic forecasts in real-time operation and analysis of trust and security requirements of data-driven methods for integrating new technologies into business processes (M24)
- D 3.4: Documentation and communication of the assessment of the value of probabilistic forecasts in selected markets, bidding strategies (M24)
- D 3.5: Summary of use cases, such as forecasting and operation & maintenance of wind power plants to show benefits of data sharing across the energy value chain (M15)
- D 3.6: Convene workshop on extreme power system events (M42)

Milestones:

- M 3.1: Setup and dissemination of webinars (M35)

5 Time Schedule with Key Dates

If the ExCo accepts this proposal, the new Task should begin on January 1, 2022, and run for four years. A kick-off meeting will be quite likely organised at the site of the Operating Agent in Risø, Denmark, during January or February 2022. The new Task will run for four years.

The Task may be further extended for one additional period as may be determined by two or more Participants, acting in the Executive Committee. Extension shall thereafter only apply to those Participants who agree to the extension.

6 Reports, Deliverables, Outreach, and Dissemination of Results

Within each Work Package a number of deliverables will be elaborated to summarize the most important results. These reports/deliverables will be composed by the Operating Agents in collaboration with the work package leaders based on inputs and reviews from the participants. The planned deliverables are listed in Table 1.

Table 2: Deliverables

No.	Deliverable	Planned
D 0.1	Website and information portal	Ongoing
D 0.2	Organization of meetings and special sessions at international conferences on wind energy	M6 – M48
D 0.3	Webinars to inform users about outcomes of the Task	M24-M36
D 1.1	Online summary of major field studies supportive of wind forecast improvement; list of available data	Ongoing
D 1.2	Report on benchmark exercise carried out in Phase II of IEA Wind Task 36 that illustrates the application of V&V	M12 (release)
D 1.3	Report on forecast horizons and the use of post-processing tools including AI	M42
D 1.4	Convene meetings with forecast centers to start the discussion of including energy metrics in NWP model upgrades.	Ongoing
D 1.5	Convene workshop and develop paper on seasonal forecasting, emphasizing hydro and storage	M19
D 2.1	Workshop and paper on state-of-the-art and future research issues in the forecasting of weather-dependent energy system variables	M7, M12
D 2.2	Workshops, reports and conference papers on methods and performance levels for key under-optimized forecasting applications	Ongoing
D 2.3	Report and conference papers on techniques to optimize the use of data science/AI tools for the forecasting of energy-application variables	M30
D 2.4	Inventory and web interface of data and tools for forecasting applications in underserved areas.	M24
D 2.5	Workshop and paper on minute-scale forecasting for hybrid power plants or wind farm control	M31, M36
D 2.6	Journal paper on uncertainty propagation through the modelling chain, based on real data	M42
D 3.1	Continued development of practical industry guidelines and application examples that can be used in Recommended Practices guidelines or	M36

	standardization documents	
D3.2	Continued work on Recommended Practice for data and instrumentation requirements for real-time forecasting (in collaboration with IEA Wind Task 32 and IEA PVPS Task 16)	M48
D 3.3	Communication and documentation of the use of probabilistic forecasts in real-time operation and analysis of trust and security requirements of data-driven methods for integrating new technologies into business processes	M24
D 3.4	Documentation and communication of the assessment of the value of probabilistic forecasts in selected markets, bidding strategies	M33
D 3.5	Summary of use cases, such as forecasting and operation & maintenance of wind power plants to show benefits of data sharing across the energy value chain	M15
D 3.6	Convene workshop on extreme power system events	M42

7 Methods of Review and Evaluation of the Work Progress

The following key milestones are defined for the follow-up of the progress of the project.

Table 3: Milestones

Milestone	WP	Milestone	Planned
M 0.1	0	First annual progress report	M12
M 0.2	0	Second annual progress report	M24
M 0.3	0	Third annual progress report	M36
M 0.4	0	Final report	M48
M 0.5	0	Kick-off Meeting	M1
M 0.6	0	Task meeting #2	M7
M 0.7	0	Task meeting #3	M13
M 0.8	0	Task meeting #4	M19
M 0.9	0	Task meeting #5	M25
M 0.10	0	Task meeting #6	M31
M 0.11	0	Task meeting #7	M37
M 0.12	0	Task meeting #8	M43
M 2.1	2	IEA Recommended Practice on Forecast Solution Selection v3	M36
M 3.1	3	Setup and dissemination of webinars	M35

8 Obligations and Responsibilities

It is noted that the main responsibilities of the Operating Agent are given in WP0 of section 4.
All of the project partners are responsible for:

- The progress of the work in correspondence with the work program in agreement with the time schedule;
- The contributions to the project deliverables and progress reports.

9 Funding

The funding principles are summarized as follows:

- Each Participant shall bear their own costs for carrying out the scientific work, including reporting and travel expenses.
- The host country or Operating Agent shall bear the costs of workshops and meetings convened in conjunction with this Task. The Operating Agent may co-fund workshop and meeting expenses including lunch or dinner, depending on the availability of funds.
- The total costs of the Operating Agent shall be borne jointly and in equal shares by the participating countries.
- Each Participant shall transfer to the Operating Agent their annual share of the costs in accordance with a time schedule to be determined by the Participants.

The Task will be centrally managed by the Technical University of Denmark (DTU, WP0) and have three WP leaders:

- DWD (DE), to coordinate WP1,
- UL Renewables (US), to coordinate WP2, and
- MINES ParisTech/ARMINES (FR), to coordinate WP3.

The WP leaders can share the function of WP lead with one or more co-lead(s).

The proposed Operating Agent is:
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10 Budget Plan

The total costs of the Operating Agents for coordination, management, reporting, and website maintenance and operation is **54 k€/yr** during a four year period, and may not exceed this level except by unanimous agreement of the Participants. The budget is shared between the Operating Agent and the WP Leads. The transfer from the Operating Agent to the WP Leads is one lump sum per year, but can also be lumped together over several years.

Table 2. Operating Agent costs

		Euro/unit	Euro/year
Meetings, coordination work	2 PM	16.000	32.000
Reporting	0,5 PM	16.000	8.000
Travel costs	2 meetings + ExCo (OA only)	2000	10.000
Other costs	Meetings, telcos, publications, website		4.000
TOTAL			**54.000**

With 12 countries signed up (we currently assume that AT, CN, DE, DK, ES, FI, FR, IE, PT, UK and US will join, with interest from IN, NO and SE), this means an annual participation fee of 4500€/year.

11 Management of Task

We envisage annual face-to-face meetings, often in connection with our own workshops or major workshops or conferences in the field, such as the US Energy System Integration Group (ESIG) Meteorology and Market Design for Grid Services Workshop, the Wind Energy Science Conference, the International Conference on Energy Meteorology, the Wind Integration Workshop or the WindEurope Conference and Exhibition. In between, an online meeting would keep track of the progress. Likewise, for the face-to-face meeting, an online meeting facility will be enabled. Both meetings will be recorded and distributed to Task members.

The main form of communication in the group will be via email, and via personal contacts during various conferences including the annual meetings.

The group of WP leaders plus the (co-)Operating Agent will meet more frequently online to discuss matters of Task management and direction, typically in preparation of the general meetings or the ExCo reporting.

12 Organisation

The Task will be centrally managed by DTU Wind Energy as a single point of contact with the IEA Wind ExCo. The WPs will be scientifically managed by the WP leads. The OA and the WP Leads for the leadership team are designated as:

Gregor Giebel - Danish Technical University (DTU) – Operating Agent
Helmut Frank – DWD, WP1 Lead
Caroline Draxl – National Renewable Energy Laboratory, WP1 Co-Lead
John Zack – UL Renewables, WP2 Lead
Jethro Browell – University of Glasgow, WP2 Co-Lead
Corinna Möhrlen – WEPROG, WP3 Lead
George Kariniotakis – MINES ParisTech/ARMINES (Centre PERSEE), WP3 Co-Lead
Ricardo Bessa – INESC TEC, WP3 Co-Lead.

The mailing list of the current phase of Task 36 contains some 250 people. Over 100 individuals attended the Task meetings. See section 14 for an up-to-date list of the most active participants.

13 Information and Intellectual Property

(a) **Executive Committee's Powers**. The publication, distribution, handling, protection and ownership of information and intellectual property arising from activities conducted under this Annex, and rules and procedures related thereto shall be determined by the Executive Committee, acting by unanimity, in conformity with the Agreement.

(b) **Right to Publish.** Subject only to copyright restrictions, the Annex Participants shall have the right to publish all information provided to or arising from this Task except proprietary information.

(c) **Proprietary Information.** The Operating Agent and the Annex Participants shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect proprietary information provided to or arising from the Task. For the purposes of this Annex, proprietary information shall mean information of a confidential nature, such as trade secrets and know-how (for example computer programmes, design procedures and techniques, chemical composition of materials, or manufacturing methods, processes, or treatments) which is appropriately marked, provided such information:

(1) Is not generally known or publicly available from other sources;

(2) Has not previously been made available by the owner to others without obligation concerning its confidentiality; and

(3) Is not already in the possession of the recipient Participant without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information, and of the Operating Agent for arising proprietary information, to identify the information as such and to ensure that it is appropriately marked.

(d) **Use of Confidential Information.** If a Participant has access to confidential information which would be useful to the Operating Agent in conducting studies, assessments, analyses, or evaluations, such information may be communicated to the Operating Agent but shall not become part of reports or other documentation, nor be communicated to the other Participants except as may be agreed between the Operating Agent and the Participant which supplies such information.

(e) **Acquisition of Information for the Task.** Each Participant shall inform the other Participants and the Operating Agent of the existence of information that can be of value for the Task, but which is not freely available, and the Participant shall endeavour to make the information available to the Task under reasonable conditions.

(f) **Reports on Work Performed under the Task.** Each Participant and the Operating Agent shall provide reports on all work performed under the Task and the results thereof, including studies, assessments, analyses, evaluations and other documentation, but excluding proprietary information, to the other Participants. Reports summarizing the work performed and the results thereof shall be prepared by the Operating Agent and forwarded to the Executive Committee.

(g) **Arising Inventions.** Inventions made or conceived in the course of or under the Task (arising inventions) shall be identified promptly and reported to the Operating Agent. Information regarding inventions on which patent protection is to be obtained shall not be published or publicly disclosed by the Operating Agent or the Participants until a patent application has been filed in any of the countries of the Participants, provided, however, that this restriction on publication or disclosure shall not extend beyond six months from the date of reporting the invention. It shall be the responsibility of the Operating Agent to appropriately mark Task reports that disclose inventions that have not been appropriately protected by the filing of a patent application.

(h) **Licensing of Arising Patents.** Each Participant shall have the sole right to license its government and nationals of its country designated by it to use patents and patent applications arising from the Task in its country, and the Participants shall notify the other Participants of the terms of such licences. Royalties obtained by such licensing shall be the property of the Participant.

(i) **Copyright.** The Operating Agent may take appropriate measures necessary to protect copyrightable material generated under the Task. Copyrights obtained shall be held for the benefit of the Annex Participants, provided however, that the Annex Participants may reproduce and distribute such material, but shall not publish it with a view to profit, except as otherwise directed by the Executive Committee, acting by unanimity.

(j) **Inventors and Authors.** Each Annex Participant will, without prejudice to any rights of inventors or authors under its national laws, take necessary steps to provide the co-operation from its inventors and authors required to carry out the provisions of this paragraph. Each Annex Participant will assume the responsibility to pay awards or compensation required to be paid to its employees according to the law of its country.

14 List of Participants

Table Countries and Organisations supporting the new task:

Country	Institution(s)
Austria	ZAMG
China	NCEPU, CEPRI, Envision, Goldwind
Denmark	DTU, DMI, ENFOR, ConWX, WEPROG, DNV, Energinet
Finland	VTT, FMI
France	MINES ParisTech / ARMINES, RTE, EDF, CNR, MeteoSwift, MetEolien, Engie Green
Germany	Deutscher Wetterdienst, ForWind-Centre for Wind Energy Research, Fraunhofer IEE, ZSW, WindForS, 4cast, Stuttgart University, Enercon
Ireland	Technical University of Dublin; University College Dublin
Portugal	INESC TEC, INEGI, LNEG, University of Porto, REN
Spain	Iberdrola Renovables, EDP Renovaveis
Sweden	TBD
United Kingdom	UK National Grid, United Kingdom Meteorological Office, Glasgow University, Reading University
USA	NREL, PNNL, NOAA, NCAR, EPRI, UL Renewables

15 References

[1] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.).] Cambridge University Press. In Press.

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

[3] Marquis, Melinda, Jim Wilczak, Mark Ahlstrom, Justin Sharp, Andrew Stern, J. Charles Smith, and Stan Calvert, 2011: Forecasting the Wind to Reach Significant Penetration Levels of Wind Energy. Bull. Amer. Meteor. Soc., 92, 1159–1171. doi: http://dx.doi.org/10.1175/2011BAMS3033.1

[4] Shaw, W. J., Berg, L. K., Cline, J., Draxl, C., Djalalova, I., Grimit, E. P., Lundquist, J. K., Marquis, M., McCaa, J., Olson, J. B., Sivaraman, C., Sharp, J., & Wilczak, J. M. (2019). The Second Wind Forecast Improvement Project (WFIP2): General Overview, Bulletin of the American Meteorological Society, 100(9), 1687-1699. Retrieved Nov 26, 2021, from https://journals.ametsoc.org/view/journals/bams/100/9/bams-d-18-0036.1.xml

[5] https://www.neweuropeanwindatlas.eu/, last accessed 22 Nov 2021

[6] IEA Wind 2013. “Forecasting Techniques”, Report: IEA R&D Wind Task 11—Topical Expert Meeting TEM #72, Milano (IT), 2013.

[7] T. Hong, P. Pinson, S. Fan (2014). Global Energy Forecasting Competition 2012. International Journal of Forecasting, 30(2), pp. 357-363. See also www.gefcom.org.

[8] Sanz Rodrigo J, Moriarty P (2015) Model Evaluation Protocol for Wind Farm Flow Models. First edition. IEA Task 31 Report to the IEA-Wind Executive Committee, June 2015

[9] R. Bessa, C. Möhrlen, V. Fundel, M. Siefert, J. Browell, S. Haglund El Gaidi, B.-M. Hodge, Ü. Cali, and G. Kariniotakis (2017): *Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry*. *Energies* **2017**, *10*(9), 1402; doi:10.3390/en10091402

[10] Yan, J., C. Möhrlen, T. Göçmen, M. Kelly, A. Wessel and G. Giebel: Uncovering Wind Power Forecasting Uncertainty Origins and Development through the whole Modelling Chain. Submitted to Renewable and Sustainable Energy Reviews.

[11] C. W. Hansen et al., "The Solar Forecast Arbiter: An Open Source Evaluation Framework for Solar Forecasting," 2019 IEEE 46th Photovoltaic Specialists Conference (PVSC), 2019, pp. 2452-2457, doi: 10.1109/PVSC40753.2019.8980713. See also https://solarforecastarbiter.org/, last accessed 22 Nov 2021