# Forecasting for the Weather Driven Energy System – A new Task under IEA Wind

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## Abstract

The energy system needs a range of forecast types for its operation in addition to the narrow wind power forecast that has been the focus of considerable recent attention. Therefore, the group behind the former IEA Wind Task 36 Forecasting for Wind Energy has initiated a new IEA Wind Task with a much broader perspective, which includes prospective interaction with other IEA Technology Collaboration Programmes such as the ones for PV, hydropower, system integration, hydrogen etc. In the new IEA Wind Task 51 (entitled "Foreacsting for the Weather Drive Energy System") the existing Work Packages (WPs) are complemented by work streams in a matrix structure. The Task is divided in three WPs according to the stakeholders: WP1 is mainly aimed at meteorologists, providing the weather forecast basis for the power forecasts. In WP2, the forecast service vendors are the main stakeholders, while the end users populate WP3. The new Task 51 started in January 2022. Planned activities include 4 workshops. The first will focus on the state of the art in forecasting for the energy system plus related research issues and be held during September 2022 in Dublin. The other three workshops will be held later during the 4-year Task period and address (1) seasonal forecasting with emphasis on Dunkelflaute, storage and hydro, (2) minute-scale forecasting, and (3) extreme power system events. The issues and conclusions of each of the workshops will be documented by a published paper. Additionally, the Recommended Practice on Forecast Solution Selection will be updated to reflect the broader perspective.

## 1 Introduction

Wind power forecasts have been used operatively since the 1990s, with solar forecasts not much later. While for small penetrations, the specific forecast for a single technology might be sufficient, a useful forecast should also include the proper correlations and hierarchical structures, spatially, temporally and across technologies.

IEA, the International Energy Agency, runs a number of Technology Collaboration Programmes (TCPs) for technology-specific collaboration in the energy field. The Wind TCP covers countries which have about 85% of the globally installed wind power. Within a TCP, a Task is a collaboration around a single topic, in our case: Forecasting. IEA Wind Task 36 "Forecasting for Wind Energy" was started in 2016, and after one extension ended in 2021. The last year was used to discuss a revamp of the Task in the light of the changes in the energy sector since 2016. The result is IEA Wind Task 51 "Forecasting for the Weather Driven Energy System", which makes the aim much broader. Task 51 started its four-year term in January 2022.

A structural change was also introduced. Whereas Task 36 had Work Packages (WPs) and sub-tasks, which at times was difficult to understand, Task 51 employs a matrix structure. The WPs are still ordered by their place in the data chain, which also means according to the type of persons or institutions. WP1 is concerned with the Numerical Weather Prediction (NWP) input to the power forecast models, which is the main ingredient for any forecast for more than a few hours ahead, and therefore collects meteorologists and meteorological institutes. WP2 aims at the process of transforming those weather inputs to power, and therefore aligns with forecast vendors. Finally, WP3 is

aligned with the end users and their decision making. Academia is present in all WPs.
However, the topics addressed by the Task are often spanning two or three of those groups. Therefore, we instituted Work Streams (WSs), which are perpendicular to the WPs. Chapter 3 will discuss those in more detail.
In Chapter 2 we present the results from the predecessor, Task 36. While most results of Task 36 were extensively discussed on other conferences and on the website, we present two results which were initiated during the last phase, but only finished in this phase: the NWP benchmark run by NREL, and the second edition of the Recommended Practice.

## 2. Results carried over from Task 36

*2.1 NWP Benchmark*

We established an open-source Python code base tailored for wind speed and wind power forecast validation, WE-Validate [1]. The code base can evaluate model forecasts with observations in a coherent manner. To demonstrate the systematic validation framework of WE-Validate, we designed and hosted a forecast evaluation benchmark exercise. We invited forecast providers in industry and academia to participate and submit forecasts for two case studies. We then evaluated the submissions with WE-Validate. Lee et al. [2] exhibit the value of a consistent procedure to evaluate wind power forecasts and emphasize the importance of using statistically robust and resistant metrics as well as equitable skill scores in forecast evaluation.

*2.2 Recommended Practice for the Implementation of Renewable Energy Forecasting Solutions*

Task 36 had produced a flagship publication, the IEA Recommended Practice on Forecast Solution Selection (during the first phase 2016-2018), stemming from the need for a document detailing the steps and pitfalls in selecting an optimal renewable energy forecasting solution for a specific application. While many of the long-term operators had a good grasp of what they needed from a short-term forecasting tool, with the increase in installed wind power world-wide, new actors entered the field, who clearly could benefit from such a guide. On the other hand, the Recommended Practice is written so that also users with a long experience might find some valuable insights.

During the second phase of Task 36 (2019-2021), the Recommended Practice was updated with feedback obtained from a number of Open Space sessions at conferences. The updates included the addition of probabilistic forecasting methods and solutions, and an enlargement to solar forecasting in collaboration with IEA PVPS (Photovoltaic Power Systems Programme) Task 16 "Solar Resource for High Penetration and Large Scale Applications" [3]. Additionally, a new chapter on the requirements of real-time measurements from the renewable plants and data communication recommendations round off the second edition. The second edition was accepted by the IEA Wind Executive Committee at the end of Task 36. The publication process however spans into the Task 51, as it will now become available as an Elsevier OpenAccess Book [4].

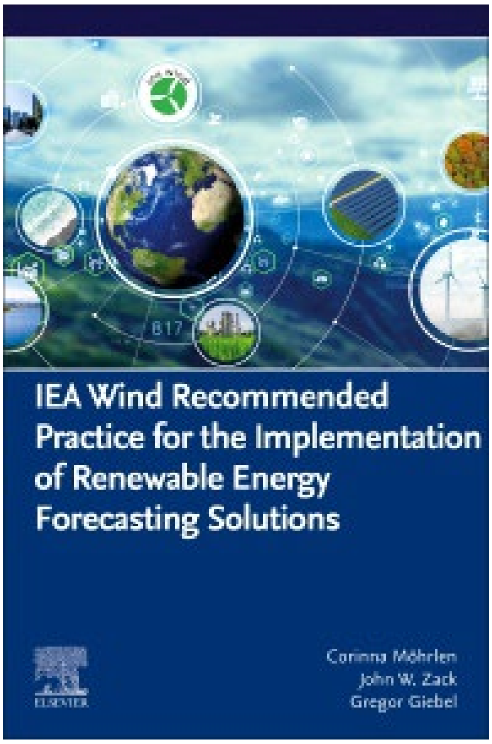


Figure 1: The IEA Wind Recommended Practice as an Elsevier OpenAccess Book.

## 3 Task 51 Work Streams

The new Task 51 runs four years, in contrast to the previous three-year periods. During those four years, online Task meetings in (Northern hemisphere) winter are augmented by in-person workshops. The first one was held on Sept 12-13, 2022, in Dublin, on the State of the Art and Research Gaps [5]. Additional workshops are planned on seasonal forecasting with emphasis on Dunkelflaute, storage and hydro in 2023, on minute scale forecasting in 2024, and on extreme power system events in 2025. All workshops are intended to result in a journal paper detailing the results.

| Work Streams: | WP1 Weather | WP2 Power | WP3 Applications | Deliverable | #, Due | Collaboration |
|---|---|---|---|---|---|---|
| Atmospheric physics and modelling (WP1) | ★ | | | List of experiments and data | D1.1, Ongoing | WMO, PVPS T16 |
| Airborne Wind Energy Systems (WP1) | ★ | | | Presentations 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<br>RecPract on Forecast Solution Selection v3 | D2.1 / M7, M12<br>M2.1 / M36 | PVPS Task 16, Hydro TCP, Hydrogen TCP, ... |
| 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<br>RecPract v3 | D 2.6 / M42<br>M48 | PVPS T16 |
| Decision making under uncertainty (WP3) | | | ★ | Training course<br>Games | M12<br>M18 | |
| Extreme power system events (WP3) | | | ★ | Workshop | D3.6 / M42 | Task 25, 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<br>Data format standard | D3.5 / M15 | ESIG<br>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 |

Figure 2: A table with the Task 51 work streams, an indication where the largest effort is expected across the WP spectrum (in green), the anchoring of the WSs (yellow stars), the deliverables for each WS, and the potential collaboration partners.

In the following, we will shortly introduce the individual WSs.

Knowing the **atmosphere** and its developments is the basis for forecasting, and detailed knowledge is especially useful for 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. A sub-topic (though in its own WS) is the forecasting for **airborne wind energy** systems, typically flying 300-600 m above ground or sea. Wind at those heights is rarely a concern for the weather services (except around airports), so a verification/validation of approaches for wind speed and direction at those altitudes still needs to be done.

**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.

In year 1, the new Task will organise a workshop on the **state of the art and future research issues** in energy forecasting [5], 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 book publications. Every WP contributes to this activity.

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 entry of the wind industry into emerging 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. Therefore, the quality of the forecast provided by the vendors is critical. This is why the WS is run by WP2. The recommended practices for the implementation of renewable energy forecasting solutions will also provide the **under-served markets** with valuable guidelines. An adaptation considering the limitations of under-served or emerging countries will be one focus area in collaboration with WP1.

On the power plant level, forecasts on the **minutes-ahead scale** 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** 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 further analysed considering the role of humans (and their perception of uncertainty and risk) through games and experiments [6], and the costs and benefits of end-users. Since the latter 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 and published in May 2022 [7]. 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.

Data-driven decision-making under risk and uncertainty is being augmented with advances in **data science** (e.g., deep learning with heterogeneous 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, with particular consideration of 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.

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.

The transformation of the energy system towards a carbon free generation, and the EU strategy for Common European data spaces and GAIA-X initiative 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 will also look at the application of emerging computational paradigms like federated learning in these use cases, and identify and analyse data transfer issues.

Without **value** for the end users, there wouldn't be a market for forecasts; however, incremental value of increased accuracy or skill is hard to assess. The value proposition is also quite country, market and user specific. E.g., a system operator's value of forecasts will be different from someone working in operations and maintenance, a utility trader or a financial speculator. Therefore, we will analyse different market structures with respect 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.

An assessment of the expected forecasting accuracy in the **design phase** for a given site was already investigated for a single case. However, since then it has been quiet. The new Task will analyse the trade-offs between normal siting of the turbines, and a process that considers differences in the expected forecast accuracy among potential sites.

# 4 Conclusion

IEA Wind Task 51 is arguably the largest international platform for exchange on renewable power forecasts. Some 350 people collaborate on many aspects of forecasting, from the production to the reception. For collaboration, please contact the Operating Agent, Gregor Giebel.

## 5 Acknowledgements

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## 6 References

**Journal articles**

[2] Lee, J.C.Y., Draxl, C. and Berg, L.K., Evaluating Wind Speed and Power Forecasts for Wind Energy Applications Using an Open-Source and Systematic Validation Framework. Available on SSRN, DOI: 10.2139/ssrn.4064500, 2022.

[6] Möhrlen, C., Bessa, R. J., & Fleischhut, N., A decision-making experiment under wind power forecast uncertainty. *Meteorological Applications*, 2022, 29(3), e2077. DOI 10.1002/met.2077

[7] Yan, J., Möhrlen, C., Göçmen, T, Kelly, M., Wessel, A. and Giebel, G., Uncovering wind power forecasting uncertainty sources and their propagation through the whole modelling chain. Renewable and Sustainable Energy Reviews, 165:112519,23, DOI: 10.1016/j.rser.2022.112519, 2022.

**Book, book chapter and manual**

[4] Corinna Möhrlen, John Zack, Gregor Giebel: IEA Wind Recommended Practice for the Implementation of Renewable Energy Forecasting Solutions. 270 pp. Elsevier Academic Press, November 1, 2022. ISBN: 9780443186813

**Websites**

[1] WE-Validate on Github, https://github.com/joejoeyjoseph/WE-Validate, accessed 18 September 2022

[3] IEA PVPS Task 16 website, https://iea-pvps.org/research-tasks/solar-resource-for-high-penetration-and-large-scale-applications/, accessed 8 September 2022

[5] 'State of the Art and Research Gaps', https://iea-wind.org/task51/task51-work-streams/ws-state-of-the-art-for-energy-system-forecasting/, accessed 8 September 2022