Final report

1. Project details

Project title	EUDP18-II IEA Wind Task 36 Phase II Danish Consortium
File no.	64018-0515
Name of the funding scheme	EUDP
Project managing company / institution	Danmarks Tekniske Universitet / DTU Vindenergi
CVR number (central business register)	30060946
Project partners	DTU Elektro, DTU Compute, DTU Management, ConWX, ENFOR, DNV GL, WEPROG, Ea Energianalyse, Energinet
Submission date	02 May 2022

2. Summary

IEA Wind Task 36 “Forecasting for Wind Energy” had as a main aim to be a discussion and communication platform for the forecasting industry, bringing together the entire value chain (from meteorology over forecast service providers to the forecast users). The EUDP support grant enabled Denmark to have a significantly larger role than warranted by the number of people among the members. Major results of the second phase (2019-2021) was an update of the IEA Recommended Practice for Forecast Solution Selection, an activity on games to motivate the use of probabilistic forecasts in contrast to the better known deterministic ones, a report on the value of forecasting in different market setups, and several papers. All of those activities had strong Danish leads or participation. The results were disseminated through workshops, most of them online, which meant that they could also be used for the IEA Wind Forecasting YouTube channel. All results can be found on https://iea-wind.org/task-36/.

IEA Wind Task 36 “Forecasting for Wind Energy” (Prognoser for Vindenergi) havde som hovedmålsætning at være et forum for diskussioner og kommunikation omkring vindenergi prognoser, hvor hele industrien og hele værdikæden (fra meteorologer over prognose-firmaer til slutbrugerne) deltager. EUDP’s økonomiske støtte har betydet at Danmark ikke alene kunne deltage, men også styre flere aktiviteter end forventeligt baseret ud fra antal deltagere fra de forskellige lande. De vigtigste resultater af fase 2 (2019-2021) er en update af IEA Recommended Practice for Forecast Solution Selection, udvikling af et spil, som kan motivere brugen af probabilistiske prognoser fremfor deterministiske, en rapport om værdien af vindprognoser afhængig af marked setup, og flere videnskabelige artikler. Alle disse aktiviteter havde stærke danske lederskab eller bidrag. Resultaterne blev kommunikeret igennem workshops (de fleste var online), hvilket betød at de også kunne bruges til IEA Wind Task 36's YouTube kanal. Alle resultater kan findes på https://iea-wind.org/task-36/.

3. Project objectives

The main objective of the EUDP support grant was to ensure a strong Danish footprint in the activities of the IEA Task. It achieved that by financing Danish participants to be able to lead certain sub-tasks, and to contribute significantly to some of the deliverables.

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4. Project implementation

The project started together with the second phase of IEA Wind Task 36 “Forecasting for Wind Energy” on January 1, 2019. The original end date of December 31, 2021 was shifted by three months to March 31, 2022. The original partners largely were continuing throughout the project, but Pierre Pinson, initially professor at DTU Elektro, shifted to DTU Management in 2020, and the partners agreed to keep him (and not DTU Elektro) as a partner. Therefore, DTU Elektro sent a final project account covering the period up to December 31, 2020 and left the project. This change, along with a number of budget changes largely due to Covid, was agreed in June 2021. One larger change was the use of the unused travel budget (again, due to Covid most Task meetings as well as the relevant conferences were held online) for a book edition with Elsevier of the Recommended Practice on Forecast Solution Selection version 2, which is the flagship publication from this Task.

The Task had 6 project meetings, the first three in Vienna, Lyngby and Glasgow, while the last three meetings were held online due to Covid. All meetings had several Danish participants.

The contract lists the following milestones (delivery dates are added according to the GANTT chart delivered in the proposal):

- M1.1 Annual summary of field studies #1 (Month 12 (the original Gantt says 11, that is an error))
- M1.2 Annual summary of field studies #2 (Month 24)
- M1.3 Annual summary of field studies #3 (Month 36)
- M2.1 Version 2 of IEA Recommended Practice on Forecast Solution Selection (Month 24) -> M36
- M2.2 WP1 Benchmark exercise defined **(Month 6) -> M24**
- M2.3 Forecast data and evaluation protocol (Month 18) -> M24
- ~~M3.1 Report on use cases for probabilistic forecasts~~ (Month 24) -> becomes part of M2.1
- M3.2 Position paper regarding the use of probabilistic forecasts (Month 36)
- M3.3 Recommended Practice for data and instrumentation requirements for real-time forecasting (Month 24) -> M36
- M3.4 Setup and dissemination of webinars (Month 36)

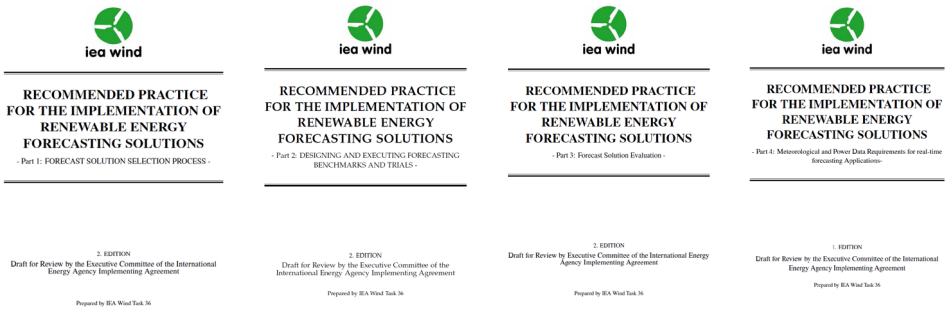
While some milestones were changed during the period of the project, mainly due to a different opinion of what made sense for Task 36, all milestones contained in the last change request were delivered. The red colour in M2.2 was for a milestone outside our control, no Danish participant was involved in the setup of the benchmark exercise. In retrospect, this milestone should not have been taken over from the IEA Task into the EUDP project.

5. Project results

IEA Wind Task 36 Phase II set out to continue the collaboration between the relevant stakeholder groups in wind power forecasting for the energy system. Specific results were worked on with the effort of Danish members as follows.

The largest effort went into the update and expansion of the **IEA Recommended Practice for Forecast Solution Selection**. While version 1 already worked well for many groups, version 2 (now called Recommended Practice for the Implementation of Renewable Energy Forecasting Solutions) expands the scope with solar forecasts (for which we collaborated with IEA PVPS Task 16), probabilistic forecasts and a fourth part on how to use real-time measurements. This last part also contains a description of useful data transfer standards, and classifies those according to complexity. Advanced users can get a fully specified API, while users with a smaller IT team will probably go for the other, simpler solution.

The first part of the series, “Forecast Solution Selection Process”, deals with the design of the selection process and the background information necessary to collect and evaluate when developing or renewing a forecasting solution. The second part, “Benchmarks and Trials”, offers recommendation on how to best conduct benchmarks and trials in order to evaluate the relative performance and the "fit-for-purpose" of forecasting solutions. The third part, “Forecast Evaluation”, provides information and guidelines for the effective evaluation of the performance of forecasts and forecast solutions. The fourth part, which has been added in the second version, provides recommendations for the design, set-up, maintenance of meteorological and power generation data gathering systems to optimally support the production of generation forecasts.



WEPROG (Corinna Möhrlen) led the overall process and contributed significant parts of the writing, while ENFOR was the lead for the data issues (Mikkel Westenholz and now Jeff Lerner), and mapped the existing data standards and their distribution into recommendations in part one of the series. The work developed two different levels of data definitions, one for novice users (essentially a glossary of terms and a simple spreadsheet) and one for advanced users based on the IEC and ENTSO-E Common Information Model with and JSON schema, which e.g. has also been used in the US Department of Energy (DOE) funded Solar Forecast Arbiter project. Other partners either contributed with text, or with a final review of the 300+ page report. The Recommended Practice was also subject of several dissemination activities, amongst others a dedicated

poster and conference articles and oral presentations on all three Wind Integration Workshops throughout the project period (2019, 2020, 2021).

Early in the Task, at the last in-person workshop held by the Task in Glasgow in January 2021, WEPROG presented in collaboration with the German Max-Planck Institute on Human Development (MPIB) an initiative on "probabilistic forecasting games and experiments". The first “game” that was setup by the team of forecast provider (WEPROG) and cognitive scientists from the MPIB was designed and ran as a ``decision game" to demonstrate the potential benefits of uncertainty forecasts in a realistic - although simplified – problem. Here, an energy trader had to decide whether to trade 100% or 50% of the energy of an offshore wind park on a given day based on deterministic and probabilistic uncertainty day-ahead forecasts. The focus thus was on a decision-making process dealing with extremes that can cause high costs in form of security issues in the electric grid for system operators, or high monetary losses for traders, who have bid a power production into the market that failed to be produced due to high-speed shutdown of the wind turbines. The first experiment aimed to investigate existing psychological barriers in the industry to adopt probabilistic forecasts and to better understand human decision processes. In the first game, there were 105 participants, mostly experts in the energy industry or from the meteorological community with relation to the energy industry. Although the experiment was simplified, it still provided a realistic scenario for many decision makers in the industry, and for this reason was well received by the participants as an exemplary application for the use and application of probabilistic forecasts from a physical-based ensemble weather prediction system, and considered a useful tool for training purposes.

The second experiment followed the structure of behavioural decision experiments in social science in order to also study communication and knowledge gaps by simulating a real-time problem for specific user groups. This experiment does not only request to make a decision, but also investigates the confidence participants have at each decision with a specific question after each decision. The amount of cases has also been increased from 12 to 20. That means, participants are randomised presented with 20 cases to make decisions based on deterministic forecast and 20 on probabilistic ensemble forecasts, inclusive a confidence choice between 50 and 100% for each decisions. With this split and randomisation of probabilistic and deterministic cases the team will be able to study the differences in decision making in difficult and less difficult situation and how the confidence changes among participants by using probabilistic or deterministic information. Along with the ”game” that is played, it is envisaged with this setup by the team to investigate a number of questions to gain insights into the behavioural effects from failures and successes. In other words, from the new experiment, the psychological aspects in decision-making can be studied.

The list of masts (subtask 1.1) and the list of experiments (subtask 1.2) was kept updated throughout the period.

The work has been orally presented at 2 Wind Integration Workshops in 2020 and 2021 with 2 conference articles, won a poster award at the Wind Europe Electric City conference in Copenhagen in 2021 and is published in a peer-reviewed conference article. A peer-reviewed journal article of the first experiment has been submitted in August 2021 and accepted for publication by Meteorological Applications in 2022.

Scientific Output

There were several peer-reviewed conference and journal articles coming out as results of the IEA Task collaboration and/or the EUDP support grant. Subtasks 2.2, and 3.1 submitted scientific articles and subtask 2.3 submitted a review article, all with strong Danish participation and an acknowledgement to the EUDP project. EUDP funded participants are highlighted with bold font:

Jie Yan, **Corinna Möhrlen, Tuhfe Göçmen, Mark Kelly**, Arne Wessel, **Gregor Giebel:** *Uncovering wind power forecasting uncertainty origins and development through the whole modelling chain*. The paper has just (April 2022) been accepted for publication. Gregor Giebel (DTU) is the corresponding author. The paper discusses the sources of uncertainty, the relative impacts, and the propagation of the uncertainty through the

entire modelling chain. The paper is a qualitative overview, while we want to write a part 2 with quantitative modelling.

Corinna Möhrlen, Ricardo Bessa and Nadine Fleischhut, *A Decision-Making Experiment under Wind Power Forecast Uncertainty. Submitted to MetApplications in August 2021 and accepted for publication in March 2022.*

***Corinna Möhrlen,* Gregor Giebel**, Ricardo J. Bessa and Nadine Fleischhut, *How do Humans decide under Wind Power Forecast Uncertainty — an IEA Wind Task 36 Probabilistic Forecast Games and Experiments initiative, J. Phys.: Conf. Ser. 2151 012014, DOI 10.1088/1742-6596/2151/1/012014, 2022*

DTU Compute published a paper on forecast evaluation:
Bjerregaard, M. B., Møller, J. K., & **Madsen, H**. (2021). *An introduction to multivariate probabilistic forecast evaluation*. **Energy and AI**, 100058. https://doi.org/10.1016/j.egyai.2021.100058

Corinna Möhrlen, John Zack and **Gregor Giebel**, *Recommended Practice for the Implementation of Renewable energy Forecasting*, Open Access Book by Elsevier Publisher. Accepted in January 2022.

Ea Energianalyse did an analysis of the value of forecasting. The analysis studies imbalance settlement according to “one-price” model in day-ahead and balancing markets, as this will be the future default model to prevail in Europe. This report focuses on the value of wind power forecasts for a wind power plant owner. The value is assessed for different bidding strategies in the day-ahead and balancing market. Ea Energy Analyses: Value of Forecast for a wind power plant Owner. Project report, IEA Wind Task 36, December 2021. 36 pp.

On 15 Dec, 2021, a final workshop was held for the Danish participants. Unfortunately, it had to be held online. The program was:

10:00 Gregor Giebel (DTU Wind Energy): Welcome, and overview of Task 36 plus an outlook to Task 51 (i.e., Phase III)
10:25 Jana Fischereit (DTU Wind Energy): Wind Farms in HARMONIE
10:50 Corinna Möhrlen (WEPROG): The Recommended Practice on Renewable Power Forecast Selection
11:20 Mads Esben Hansen (ENFOR): Wind Power Forecasting using Spatial Hierarchies
11:50 Peter Børre Eriksen (Ea Energianalyse): The Value of Wind Power Forecasting in the Markets
12:20 Roundup, AOB

The Task was presented numerous times at workshops with special session and a mini-symposium with presentations by the Danish participants Gregor Giebel (DTU), Corinna Möhrlen (WEPROG), Jeff Lerner and Mikkel Westenholz (ENFOR), Mathias Bilcher Bjerregård and Henrik Madsen (DTU Compute).

The following lists the workshops and activities of the group over the three year project period (Jan 2019-Mar 2022).

2019

ICEM 2019, DTU Campus, Lyngby, 26 June 2019

G. Giebel, W. Shaw, H. Frank, C. Draxl, J. Zack, P. Pinson, C. Möhrlen, G. Kariniotakis, R. Bessa, IEA Wind Task 36 “Wind Energy Forecasting”, Open Space Workshop

John Zack, Corinna Möhrlen, Jeff Lerner , Jethro Browell, Jakob Messner, Caroline Draxl, Recommended Practices Guidelines for Forecast Solution Selection

18th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plant, Dublin, Ireland, October 16.-18, 2019

G. Giebel, W. Shaw, H. Frank, C. Draxl, J. Zack, P. Pinson, C. Möhrlen, G. Kariniotakis, R. Bessa, IEA Wind Task 36: The New Phase for the Wind Power Forecasting Task

C. Möhrlen, U. Vestergaard, J. Ryan, K. Conway, S. Griffin, Probabilistic forecasting tools for high-wind penetration areas: an Irish case study

2020

Wind Integration Workshop 2020, Session 6A: IEA Wind Task 36: Raising the Bar on Information Transparency and Recommended Practices for Wind Power Forecasting

> Session Chair Gregor Giebel (DTU Wind Energy, Denmark)

G. Giebel (DTU Wind Energy, Denmark), W. Shaw (PNNL, United States), H. Frank (Deutscher Wetterdienst DWD, Germany), C. Draxl (NREL, United States), J. Zack (UL Services Group, United States), P. Pinson (DTU Elektro, Denmark), C. Möhrlen (WEPROG, Denmark), G. Kariniotakis (Mines ParisTech, France), R. J. Bessa (INESC TEC, Portugal): *IEA Wind Task 36 Forecasting – An Overview* (Submission-ID WIW20-128)

C. Draxl, J. Lee (National Renewable Energy Laboratory – NREL, United States), W. Shaw, L. Berg (Pacific Northwest National Laboratory, United States): *Validation of Numerical Model Improvements through Public Data Sets and Code* (Submission-ID WIW20-124)

J. Zack (UL Services Group, United States), C. Möhrlen (WEPROG, Denmark): *IEA Wind Task 36: Practical Application Examples from the Recommended Practices for Forecast Solution Selection* (Submission-ID WIW20-108)

J. Lerner, M. Westenholz (ENFOR, Denmark) *Wind Power Forecasting Data Definitions and Exchange Standards – An Approach for a Recommended Practice Built upon International Standards and an Eye Towards the Future* (Submission-ID WIW20-126)

C. Möhrlen (WEPROG, Denmark), N. Fleischhut (Max-Planck Institute for Human Development, Germany), R. J. Bessa (INESC TEC, Portugal): *Insight on Human Decision-making from Probabilistic Forecast Games and Experience: an IEA Wind Task 36 initiative* (Submission- ID WIW20-98)

2021

Gregor Giebel, Will Shaw, Helmut Frank, Caroline Draxl, John Zack, Pierre Pinson, Corinna Möhrlen, George Kariniotakis, and Ricardo Bessa: *IEA Wind Task 36*. Invited talk on the Industrie- und Forschungsplattform Prognose meeting, online, 3 February 2021

Gregor Giebel, Will Shaw, Helmut Frank, Caroline Draxl, John Zack, Pierre Pinson, Corinna Möhrlen, George Kariniotakis, and Ricardo Bessa: *IEA Wind Task 36 – International Collaboration on Forecast Improvements*. PICO talk on the virtual European Geophysics Union General Assembly, 19-30 April 2021.

Wind Energy Science Conference, 25-28 May 2021, Mini-symposium Wind Power Forecasting.
Gregor Giebel, Will Shaw, Helmut Frank, Caroline Draxl, John Zack, Pierre Pinson, Corinna Möhrlen, George Kariniotakis, and Ricardo Bessa: *IEA Wind Task 36 – Forecast and Usage Improvements*. Talk on WESC 2021
Corinna Möhrlen, Nadine Fleischhut, Ricardo Bessa, Gregor Giebel: *Overcoming psychological Barriers of using Probabilistic Power Forecasting with Games and Experiments*. Talk on WESC 2021.

Wind Europe Electric City 2021, Copenhagen, 23.-25.11.2021
Corinna Möhrlen, Ricardo Bessa, Gregor Giebel, Nadine Fleischhut, “How do Humans decide under Wind

Power Forecast Uncertainty?", Session "Forecasting" on 25th Nov. 2021 11:45 – 12.30 Auditorium 15
Poster **Award Winner!**

EMS 2021 – European Meteorological Society annual Meeting
ES2.2 Dealing with Uncertainties
Lightning talks | Mon, 06 Sep, 14:00–15:30 (CEST), Tue, 07 Sep, 14:00–15:30 (CEST)

Corinna Möhrlen, Communicating warnings for extreme events: use-case of a high-speed shutdown warning system for a system operator with high wind power penetration, EMS2021-495.

Corinna Möhrlen, Ricardo Bessa, and Gregor Giebel , IEA Wind Task 36 "Probabilistic Forecasting Games and Experiments" Initiative, EMS2021-500.

ESIG 2021 Meteorology & Market Design for Grid Services Workshop — ONLINE —
Session 3: Probabilistic Forecasting: State-of-Art and Use in Operations, Tuesday, June 8 — 3:00 – 5:00 p.m. (US-EDT)
Ensemble-Based Dynamic Ramping Reserve Forecasts: An Irish Case Study
Corinna Möhrlen, Presentation and video

Session 4: Global Advances in Forecasting, Thursday, June 10 — 3:00 – 4:30 p.m. (US-EDT)
IEA Wind Task 36 Forecasting Recommendations
Gregor Giebel, DTU Wind Energy, Denmark, Presentation and video

2022

American Meteorological Society Annual Meeting, Online, 26th Jan. 2022 1:30 PM – 1:45 PM EST
13th Conference on Weather, Climate, and the New Energy Economy
11.1 – Best Practices for the Selection of Optimal Forecast Solutions for Renewable Electricity Generation Applications (Core Science Keynote)
Dr. John W. Zack and Dr. Corinna Möhrlen

There was dissemination of the IEA Task especially on LinkedIn, but also on the YouTube channel, the website and in personal contacts.

6. Utilisation of project results

The major result in the Recommended Practice is already taken up by industry, even some outside the Task (the company in question has been invited to join). In lack of standards for the implementation of renewable, especially wind energy forecasting into system operation, trading and operation and maintenance, the main aim of the recommended practice is to harmonise processes across the industry and thereby assist both providers and end-users to work along commonly accepted processes on a global basis. Without a common understanding and common definitions of methods and processes, the targets set by governments all over the globe cannot be reached.

The scientific articles and the dissemination of work progress at all major and minor workshops and conferences brings scientists, developers and end-users together to discuss challenges and form initiatives to overcome barriers, which enables steady progress alongside new technical developments and policies that need

adaptation. Without an international collaboration many of these tasks would not be able to be solved in an efficient and sustainable way.

The participation of DNV in the Task has assisted in the continuous improvement of DNV's forecasting systems being integrated with all the other international task members has been a huge benefit.

7. Project conclusion and perspective

The main goal of the EUDP project, namely a strong Danish participation, was fulfilled well. For the Task, the Danish partners were responsible for or contributed to most results, influenced the work and pushed boundaries by introducing a first pre-standard with the recommended practice guidelines. The professional publication of the guidelines through Elsevier publisher with two of the three main authors being EUDP funded, will enhance the integration of the guideline into the industry.

Task 36 had come to the end of its life cycle, and is now replaced (after a long consultation process) by Task 51 “Forecasting for the Weather Driven Energy System”. The scope is much broader than just wind power forecasting, and instead of the division into sub-tasks, which were part of the work package descriptions, Task 51 has work streams. A peculiarity of those is that we will collaborate with many other Tasks inside and outside the IEA Wind TCP. A prominent partner is IEA PVPS Task 16 for the solar component, but also within hydropower, hydrogen, biomass and others there is interest in collaboration. Internally, links are established to Tasks 25 “Large scale integration”, 32 “Lidar”, 44 “Wind Farm Flow Control”, 48 “Airborne Wind Energy” and 50 “Hybrid Wind Power Plants”.

All Work Streams:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Atmospheric physics and modelling	★			List of experiments and data	D1.1, Ongoing	WMO, PVPS T16
Airborne Wind Energy Systems	★			Presentations on workshops	Part of D2.1	Task 48 Airborne Wind Energy
Seasonal forecasting	★			Workshop / Paper	D1.6 / M19	Hydro TCP, Hydrogen TCP, Biomass TCP
State of the Art for energy system forecasting		★		Workshop / Paper RecPract on Forecast Solution Selection v3	D2.1 / M7, M12 M2.1 / M36	PVPS Task 16, Hydro TCP, Hydrogen TCP, …
Forecasting for underserved areas		★		Public dataset	D2.4 / M24	WMO
Minute scale forecasting		★		Workshop / Paper	D2.5 / M31, M36	Wind Tasks 32 Lidar, 44 Farm Flow Control and 50 Hybrids
Uncertainty / probabilistic forecasting			★	Uncertainty propagation paper with data RecPract v3	D 2.6 / M42 M48	PVPS T16
Decision making under uncertainty			★	Training course Games	M12 M18	
Extreme power system events			★	Workshop	D3.6 / M42	Task 25, ESIG, IEA ISGAN, PVPS T16, G-PST
Data science and artificial intelligence			★	Report	D2.3 / M30	
Privacy, data markets and sharing			★	Workshop / Paper Data format standard	D3.5 / M15	ESIG IEEE WG Energy Forecasting
Value of forecasting			★	Paper	D 3.4 / M33	
Forecasting in the design phase			★			Task 50 (hybrids), PV T16, hydrogen TCP

8. Appendices

IEA Wind TCP Annual Report 2019

IEA Wind TCP Annual Report 2020

Homepage: ieawindforecasting.dk, but we are in the process of moving to iea-wind.org/task36, and in principle are moving on to iea-wind.org/task51.