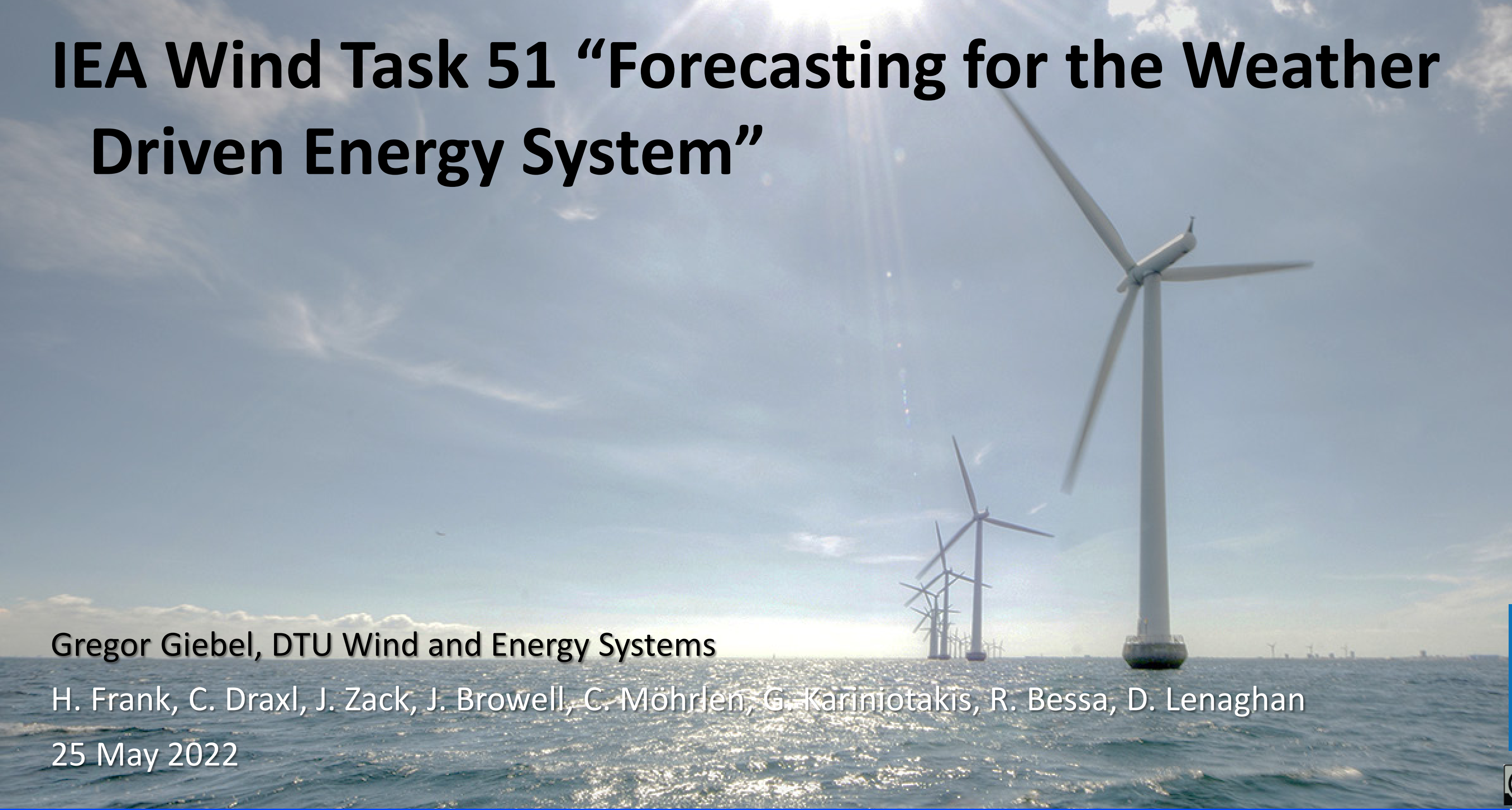
IEA Wind Task 51 “Forecasting for the Weather Driven Energy System”



Gregor Giebel, DTU Wind and Energy Systems

H. Frank, C. Draxl, J. Zack, J. Browell, C. Möhrlen, G. Kariniotakis, R. Bessa, D. Lenaghan

25 May 2022

Task Objectives & Expected Results

Task Objective is to encourage improvements in:
1) weather prediction
2) power conversion
3) use of forecasts

Task Organisation is to encourage international collaboration between:
- Research organisations and projects
- Meteorologists
- Forecast providers
- End-users and stakeholders

Task Work is divided into 3 work packages:
WP1: Weather Prediction Improvements
WP2: Power and Uncertainty Forecasting
WP3: Optimal Use of Forecasting Solutions

Current Term: 2022-2025

IEA Best Practice Recommendations for the Selection of a Wind Forecasting Solution v2: Set of 4 Documents

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RECOMMENDED PRACTICE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

- Part 1: FORECAST SOLUTION SELECTION PROCESS -

2. EDITION

Draft for Review by the Executive Committee of the International Energy Agency Implementing Agreement

Prepared by IEA Wind Task 36

Part 1: Selection of an Optimal Forecast Solution

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RECOMMENDED PRACTICE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

- Part 2: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS -

2. EDITION

Draft for Review by the Executive Committee of the International Energy Agency Implementing Agreement

Prepared by IEA Wind Task 36

Part 2: Design and Execution of Benchmarks and Trials

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RECOMMENDED PRACTICE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

- Part 3: Forecast Solution Evaluation -

2. EDITION

Draft for Review by Executive Committee of the International Energy Agency Implementing Agreement

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Part 3: Evaluation of Forecasts and Forecast Solutions

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RECOMMENDED PRACTICE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

- Part 4: Meteorological and Power Data Requirements for real-time forecasting Applications-

1. EDITION

Draft for Review by the Executive Committee of the International Energy Agency Implementing Agreement

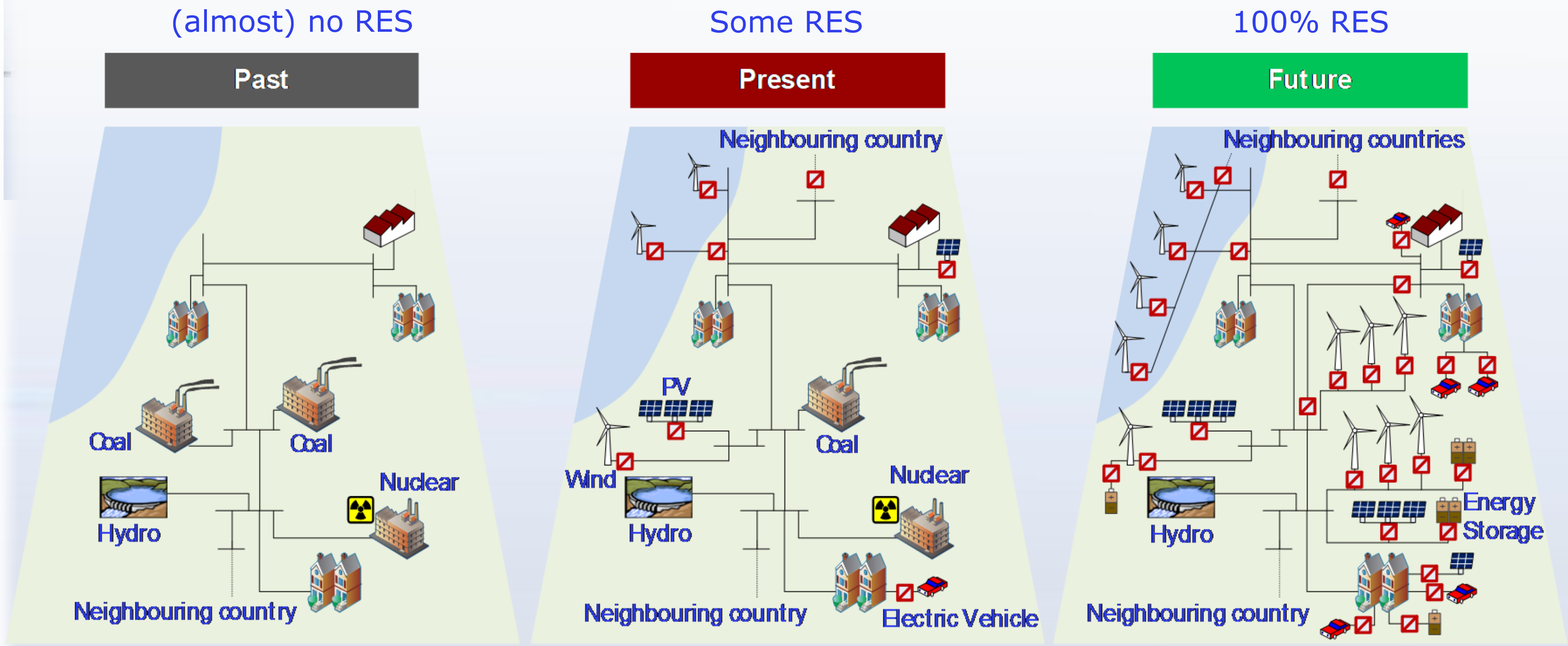
Prepared by IEA Wind Task 36

Part 4: Data Requirements for Real-time Applications

Finalising now - also as book!

Introduction: https://www.youtube.com/watch?v=XVO37hLE03M

From Wind Integration to Energy Systems



Forecasting needs: little

All RES seperately

All RES with correct correlations and longer time scales

Slide design: Ömer Göksu and Nicos Cutululis

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 RecPract on Forecast Solution Selection v3	D2.1 / M7, M12 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 RecPract v3	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	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 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

WS State of the Art and Research Gaps

WS:	WP1 Weather	**WP2 Power**	WP3 Applications	**Deliverable**	**#, Due**	**Collaboration**
State of the Art for energy system forecasting (WP2)				Workshop / Paper RecPract on Forecast Solution Selection v3	D2.1 / M7, M12 M2.1 / M36	PVPS Task 16, Hydro TCP, Hydrogen TCP, …

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. Every WP contributes to this activity.

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=Summer 2022, M12=Dec 2022) -> **September in Dublin!**

M 2.1: Version 3 of IEA Recommended Practice on Forecast Solution Selection (M36=Dec 2024)

Work stream Atmospheric Physics

WS:	**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

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.

D 1.1: Online summary of major field studies supportive of wind forecast improvement; list of available data (ongoing)

Image source: NOAA

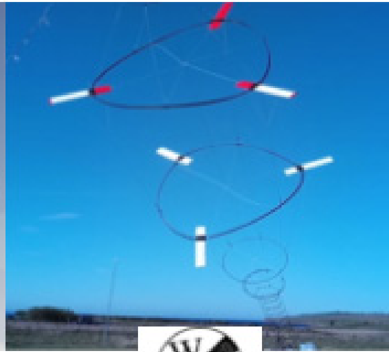
Work stream Airborne Wind Energy


(b) AWE farm

Work Streams:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Airborne Wind Energy Systems (WP1)				Presentations on workshops	Part of D2.1	Task 48 Airborne Wind Energy

- Novel topic, winds in 300-600m height
- Mapping state of the art on workshop
- Collaboration with Task 48

Image source: Task 48 presentation on IEA Wind ExCo 88, Nov 2021



WS Seasonal Forecasting

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Seasonal forecasting (WP1)				Workshop / Paper	D1.5 / M19	Hydro TCP, Hydrogen TCP, Biomass TCP

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.

D 1.5: Convene workshop and develop paper on seasonal forecasting, emphasizing hydro and storage (M19, summer 2023)

Data source SEAS5 ensemble mean from C3S ECMWF | Reference 1993-2016 | Run

Background image: Vortex FdC

Wind Speed Anomaly @ 100m - [%]

WS Uncertainty / Probabilistic FC / Decision making

WS:	WP1 Weather	WP2 Power	**WP3 Applications**	**Deliverable**	**#, Due**	**Collaboration**
Uncertainty / probabilistic forecasting / decision making under uncertainty (WP3)				Uncertainty propagation paper with data	D 2.6 / M42	PVPS T16
				Games	M18	
				RecPract v3	M48	
				Training course	M12	

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.

D 2.6: Paper on uncertainty propagation in the modelling chain, using quantitative data (M42)

M 2.1: Version 3 of IEA Recom. Practice on Forecast Solution Selection (M36)

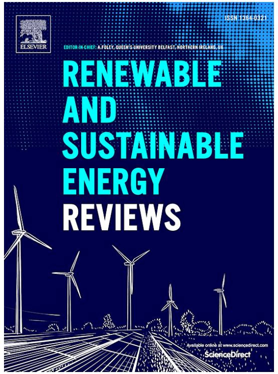
WS Uncertainty / Probabilistic FC / Decision making:

Uncertainty Propagation throughout the model chain with real data

One review paper is in press. Highlights include:

Jie Yan, Corinna Möhrlen, Tuhfe Göçmen, Mark Kelly, Arne Wessel, Gregor Giebel

- **Uncertainty sources** are defined and described throughout the chain of forecast modelling.
- **Uncertainty mitigation** approaches for each type of uncertainty source **from planning, operation to market phase** are reviewed.
- An example of uncertainty validation is presented and discussed.



Uncovering wind power forecasting uncertainty origins and development through the whole modelling chain★,★★

Jie Yan[a], Corinna Möhrlen[b], Tuhfe Göçmen[c], Mark Kelly[c], Arne Wessel[d] and Gregor Giebel[c,*,6,3]

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ABSTRACT

Wind power forecasting has been supporting operational decision-making for power system and electricity markets since 30 years. Efforts of improving the accuracy and/or certainty of wind power forecasts, either deterministic or probabilistic, are continuously exerted by academics and industries. Forecast errors and associated uncertainties, which propagate through the whole forecasting chain, from weather provider to the end user, cannot be eliminated completely due to many reasons; for instance, endogenetic randomness of weather systems and varying wind turbine performance. Therefore, understanding the sources of uncertainty and how these uncertainties propagate throughout the modelling chain is significant to implement more rational and targeted uncertainty mitigation strategies and standardise the uncertainty validation. This paper presents a thorough review of the uncertainty propagation through the modelling chain, from the planning phase of the wind farm and the forecasting system through the operational phase and market phase. Moreover, the definition of the uncertainty sources throughout these phases build the guiding line of uncertainty mitigation throughout this review. In the end, a discussion on uncertainty validation is provided along with some examples. Highlights of this paper include: 1) forecasting uncertainty exists and propagates everywhere throughout the entire modelling chain and from planning phase to market phase; 2) the mitigation efforts should be exerted in every modelling step; 3) standardised uncertainty validation practice and global data samples are required for forecasters to improve model performance and for forecast users to select and evaluate the model's output.

1. Introduction

High penetration of wind power has been recognised globally as one of the most important features of current and future sustainable power systems. The natural randomness and variability of the wind itself can aggravate negative impacts of wind power on power system operation and market trading, which strengthens the significance of forecasting technology. Wind power forecasting (WPF) started more than three decades ago [Brown et al., 1984], with the first operational forecasting tools arriving at system operation level some 10 years later at the Danish transmission system operator ELSAM [Giebel et al., 2011]. Since then, researchers have been making continuous efforts to improve the forecasting accuracy and reliability.

It is impossible to achieve perfect predictions of wind power at any given time or location, due to chaotic atmospheric motions having temporal and spatial scales that typically span more than six orders of magnitude [Lorenz, 1969a, Slingo and Palmer, 2011, Wyngaard, 2010]. Along with the complex wind field, wind turbine performance creates nonlinear and time-varying uncertainties in wind power forecasting. To improve the value of forecasts and their usage, we practically consider three questions: why, when and to what extent the forecasting uncertainty will happen [Lange, 2003]. Accordingly, this further guides the mitigation of forecasting uncertainty. There is plenty of literature in this area, and can be clarified into following three categories.

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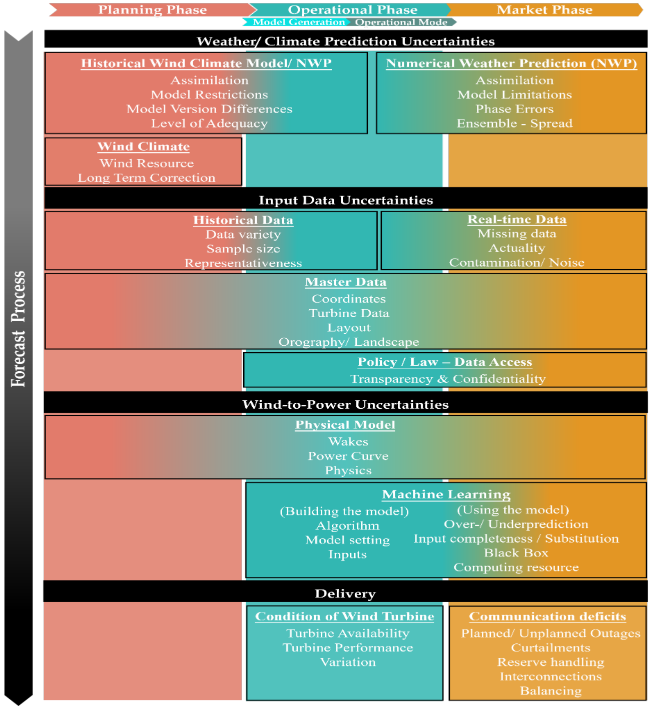
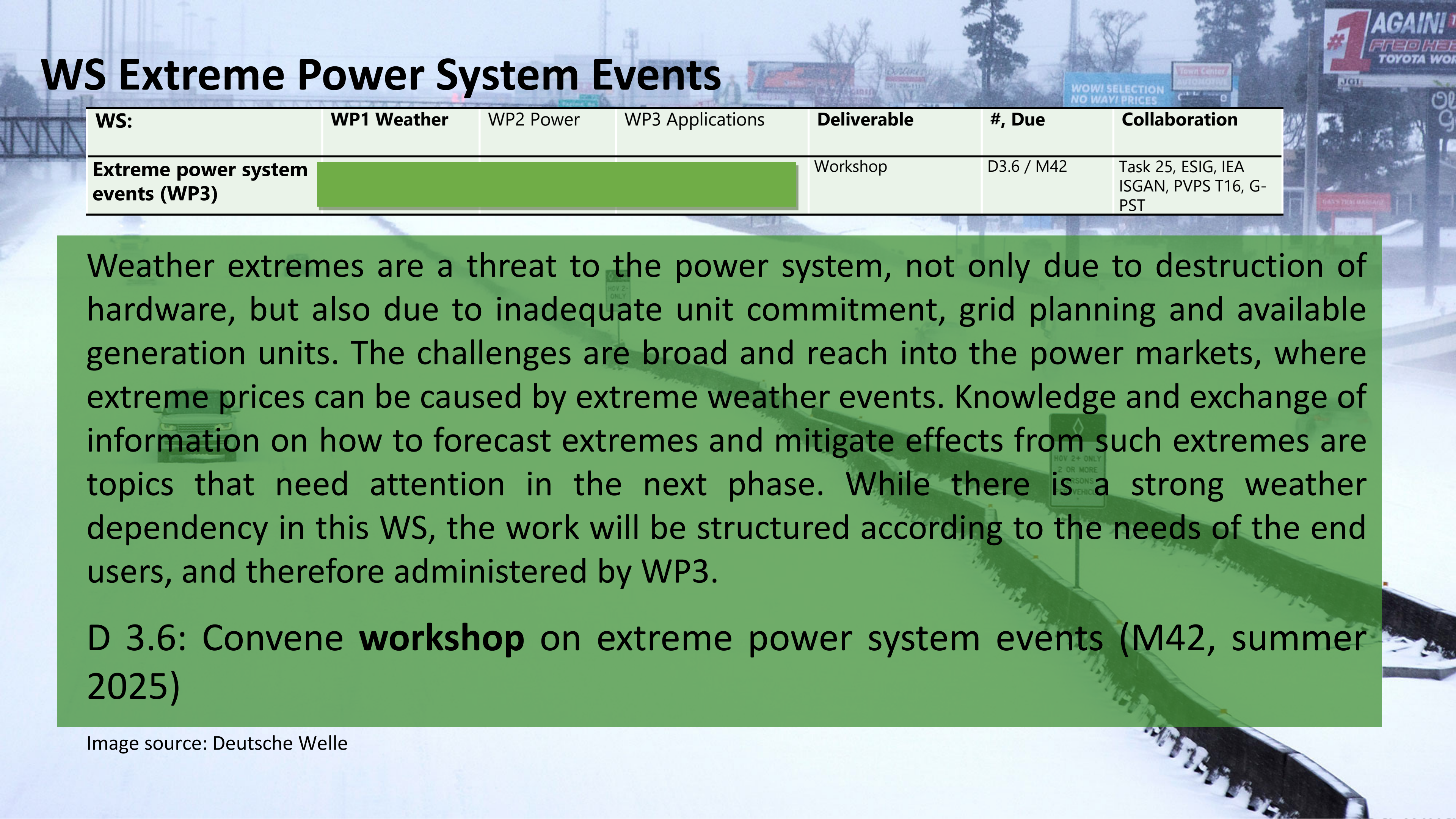
Data
Measurement
Model
Turbine
Algorithm
Weather
Policy
Wind-to-Power
Communication





WS Extreme Power System Events

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Extreme power system events (WP3)				Workshop	D3.6 / M42	Task 25, ESIG, IEA ISGAN, PVPS T16, G-PST

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.

D 3.6: Convene **workshop** on extreme power system events (M42, summer 2025)

Image source: Deutsche Welle

WS Data Science and Artificial Intelligence

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Data science and artificial intelligence (WP3)				Report or paper	D2.3 / M30	

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, 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.

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)

WS Privacy, Data Markets and Sharing

WS:	WP1 Weather	WP2 Power	**WP3 Applications**	**Deliverable**	**#, Due**	**Collaboration**
Privacy, data markets and sharing (WP3)				Workshop / Paper Data format standard	D3.5 / M15	ESIG, IEEE WG Energy Forecasting

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.

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)

WS Value of Forecasting

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Value of forecasting (WP3)				Paper	D 3.4 / M33	

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.

D.3.4: Documentation and communication of the assessment of the value of probabilistic forecasts in selected markets, bidding strategies (M24)

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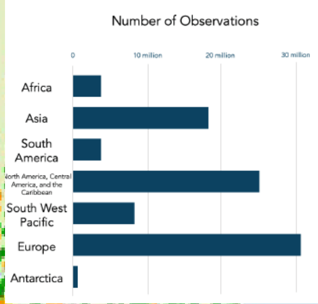
WS Forecasting for underserved areas

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Forecasting for underserved areas (WP2)				Public dataset	D2.4 / M24	WMO



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.

D 2.4: Inventory and web interface of data and tools for forecasting applications in underserved areas. (M24)

Graphics source: WMO 2021: The value of Surface-Based Meteorological Observation Data: Costs and benefits of the Global Basic Observing Network. Image source: WMO

WS Forecasting in the Design Phase

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Forecasting in the design phase (WP3)						Task 50 (hybrids), PV T16, hydrogen TCP

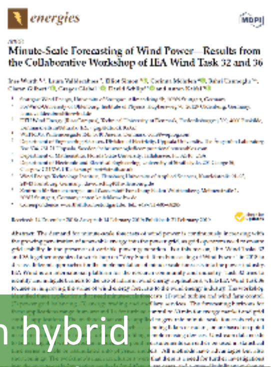
An assessment of the expected forecasting accuracy for a given site was already investigated for a single case in Europe. However, since then it has been quiet.

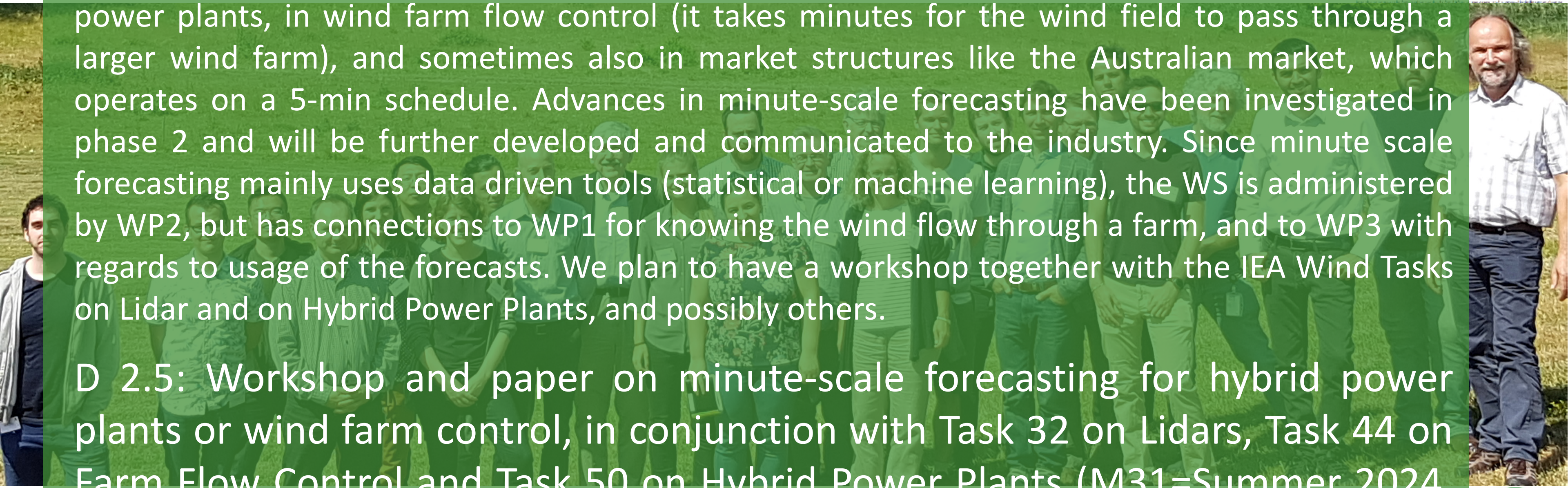
- Case in Denmark analyzed during SafeWind project

The new Task will analyse the tradeoffs between normal siting of the turbines, and the forecast capability type.

WS Minute scale forecasting

WS:	WP1 Weather	WP2 Power	WP3 Applications	Deliverable	#, Due	Collaboration
Minute scale forecasting (WP2)				Workshop / Paper	D2.5 / M31, M36	Wind Tasks 32 Lidar, 44 Farm Flow Control and 50 Hybrids, PVPS T16





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.

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=Summer 2024, M36)

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www.IEA-Wind.org/task-51 or www.IEAWindForecasting.dk

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