IEA Wind Task 36

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EGU Online 2020

Technology Collaboration Programme

by iea

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Overview

News from IEA Wind Task 36 on Forecasting:

- **Meteo benchmark coming up, info portal continuously updated**
- **End-user workshop in Glasgow**
- **Games motivating probabilistic information use**

Additional material the Annex:

- What is the International Energy Agency?
- What is short-term prediction of wind power?
- What is the role and setup of IEA Wind Task 36?
- Achievements: Information portal, Recommended Practice, papers, handouts

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
- Forecast providers
- Policy Makers
- 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: 2019-2021 (First term 2016-2018)

WP1 Meteorology Current state-of-the-Art

- Verification&Validation benchmark defined (US results to be published end of June, benchmark to be published on Atmosphere2Electrons (A2E) site)
- Continuously updating the lists, and work underway to use the collected data sets for Numerical Weather Prediction

SITE NAME	COORDINATES	ALTITUDE ABOVE MSL	TOWER HEIGHT	URL	CONTACT	DATA POLICY	DATA FORMAT	OBS. PERIOD	OTHER
Cabauw, NL	4.926° E, 51.97° N	-0.7 m	200 m	www.cesar-observatory.nl/index.php	henk.klein.baltink@knmi.nl	Cesar data policy	netCDF	2000-04-01 to previous month	
IJmuiden, NL	3.436° N, 52.848° E	0 m	92 m	www.meteomastijmuiden.nl/en /measurement-campaign/	verhoef@ecn.nl			since 2012	offshore North Sea
Risø, DK	12.088° E, 55.694° N	0 m	125 m	rodeo.dtu.dk/rodeo /ProjectOverview.aspx?&Project=5& Rnd=975820	Allan Vesth	Ask nicely		1995-11-20 -	Data measured since 1958; some months break in 2008.
Østerild, DK	8.88080° E, 57.04888° N	9 m	250 m	rodeo.dtu.dk/rodeo /ProjectOverview.aspx?&Project=17& Rnd=975820	Yoram Eisenberg	Ask nicely		2015-01-28 -	Two 250m masts in 4.3 km distance, both instrumented.

WP2 IEA Recommended Practice on Forecast Solution Selection

- Received feedback from industry, use of some concepts starts to appear in tenders
- Requires more dissemination, e.g. on Hybrid systems workshop
- Version Update (2021):
  - More input from industry
  - Filling in found omissions
  - More examples
  - Collaboration with IEA Solar Task


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EXPERT GROUP REPORT

ON

RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 1: FORECAST SOLUTION SELECTION PROCESS

1. EDITION 2019

Submitted to the
Executive Committee of the
International Energy Agency Implementing Agreement
on 13th August 2019

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EXPERT GROUP REPORT

ON

RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 2: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS

1. EDITION 2018

Submitted to the Executive Committee of the International Energy Agency Implementing Agreement
on 13th August 2018

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EXPERT GROUP REPORT

ON

RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 3: Evaluation of Forecasts and Forecast Solutions

1. EDITION 2018

To be Submitted to the
Executive Committee of the
International Energy Agency Implementing Agreement
on 1st March 2019

WP3 Optimal Use of Forecasting Solutions

- Definition of forecast error spread / confidence intervals vs forecast uncertainty
- Continued collaboration with IEC SC 8A Workgroup on Technical Report IEC63043
- Standardisation of meteorological data feeds and instrumentation for forecasting
- Value of forecasts: investigation started by analysis (ppt, paper underway) and forecast game/experiment:
  https://mpib.eu.qualtrics.com/jfe/form/SV_d5aAY95q2mGI8El
  (feel free to play it yourself - it's still open !)

WP3 End-user Workshop in Glasgow

“Maximising Value from State-of-the-art Wind Power Forecasting Solutions”

hosted by Jethro Browell at Strathclyde University, Glasgow, 21 Jan 2020

- Talks by academia and industry (e.g. UK National Grid, WindPoint, UStrathclyde)
- Open Space discussion on RP, data and forecast value
- Game on value of probabilistic forecasts *(feel free to play it - it's still open !)*: https://mpib.eu.qualtrics.com/jfe/form/SV_d5aAY95q2mGI8El
- Streamed on YouTube: https://www.youtube.com/watch?v=1NOIr7jIuXI


WP3 Forecast Games and Experiments:
Game 1: Offshore wind power decision making in extreme events

Conducted by Dr. Corinna Möhrlen, WEPROG in collaboration with Dr. Nadine Fleischhut, MPI for Human Development, Berlin

3 Postulates formed the basis for the experiment design:

(1) Success in the trading is highly dependent on the costs of the balancing power needed due to forecast errors
(2) 5% of the cases, where there are large forecast errors are responsible for 95% of the costs in a month or year
(3) Reducing these costs is more important than improving the general forecasts by ~1%

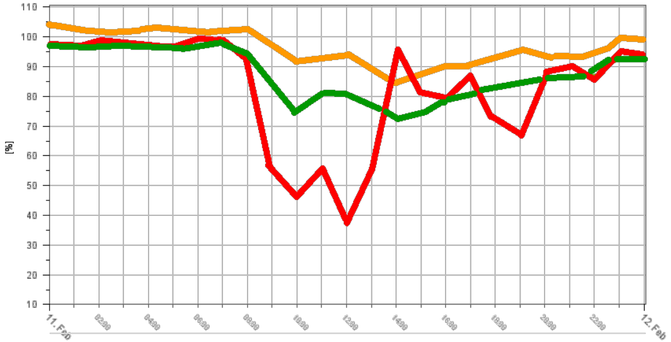
The Experiment:
Decide in 12 cases whether to trade 50% or 100% of the generating power of an offshore wind park according to an available forecast given the possibility of a high-speed shutdown, where the wind park stops generating due to excessive wind conditions.

Definition of a "high-speed shutdown" (HSSD) or "cut-off wind" event :
A high-speed shutdown event occurs typically in the wind range above 21-27m/s, mostly known as the cut-off wind threshold of 25 m/s. Note that wind turbines use both wind gusts and the mean wind to determine, whether or not they turn into high-speed shutdown (HSSD).

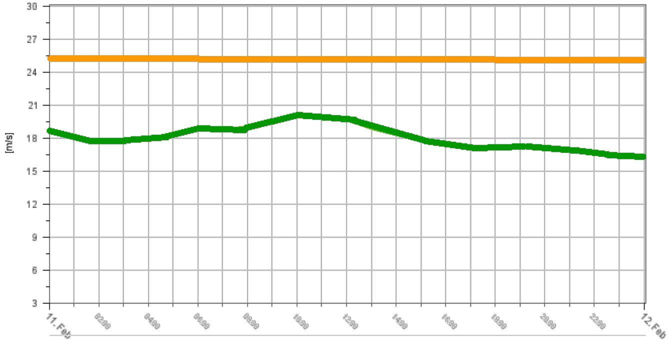
Forecast Game 1:
Offshore wind power decision making in extreme events

Type of forecasts used in the experiment:

In the experiement are determinisitic and probabilistic forecasts for the **day-ahead horizon**.
All forecasts are generated with input from NWP (numerical weather prediction) forecasts from the 00UTC cycle the day before.

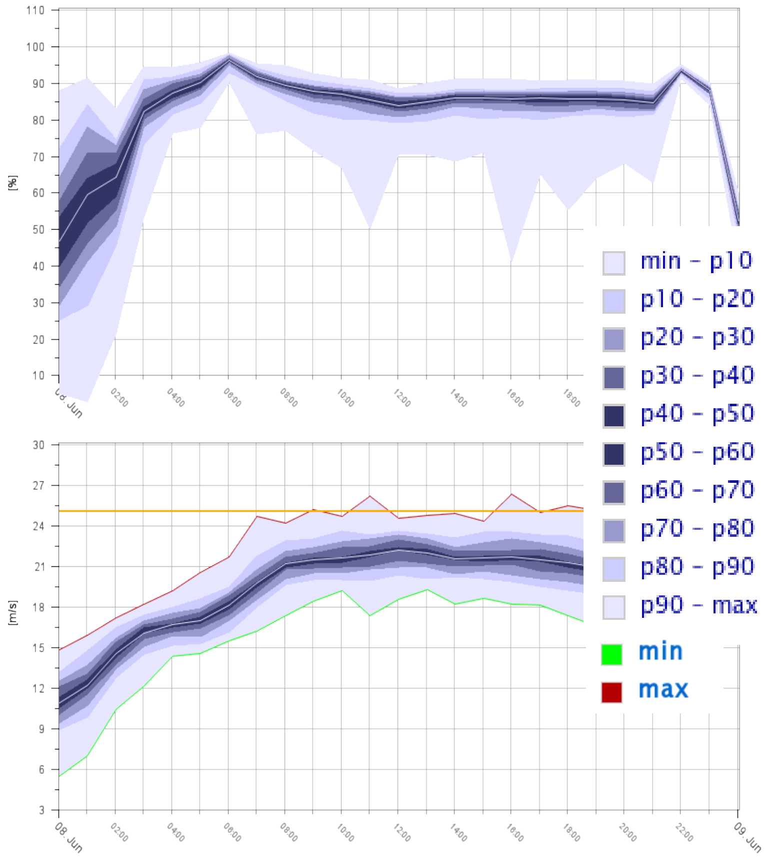


3 independent deterministic wind power forecasts in the unit [% of installed capacity] based on 3 different NWP (numerical weather prediction) models



1 wind speed forecast in the unit [m/s], which is a mean forecast from 75 ensemble members and smoother than a typical deterministic forecast. **Additionally, you see a reference line for the 25m/s threshold reference value** for high-speed shutdown or also sometimes called cut-off wind speed threshold.

Forecast Game 1:
Offshore wind power decision making in extreme events



9 wind power percentiles (P10..P90) and a mean (white line) in the unit [% of installed capacity] generated from 75 NWP forecasts of a multi-scheme ensemble prediction system.

9 wind speed percentiles P10..P90 and a mean (white line) in the unit [% of installed capacity] generated from 75 NWP forecasts of a multi-scheme ensemble prediction system.

Note: The percentiles here are physically based uncertainty bands and provide an overview of the uncertainty of the forecast.

Definition: A percentile indicats the value below which a given percentage of foreasts from the 75 available forecasts falls. E.g., the 20th percentile is the value below which 20% of the forecasts are found.

Forecast Game 1:
Offshore wind power decision making in extreme events

The cost profile

To reflect the costs of large and small errors we have defined a simplified cost function for the period, where high-speed shutdown (HSSD) can take place.

Definitions:

- the wind farm is 100MW and the spot market price is 50 Eur/Mwh.
- balance costs are equivalent to spot market prices
- The cost function will only consider your choice for the hours, where the actual generation is full load or no generation

Trading	HSSD*	No HSSD*
100%	-5.000	5.000
50%	0	2.500

* High-Speed Shutdown == cut-off winds

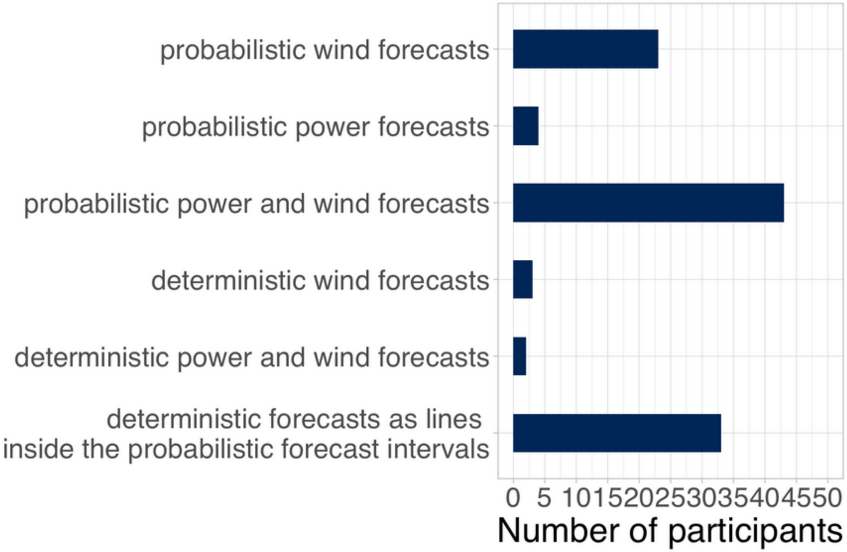
Note that trading **100% is a risky choice** that can both increase your income and loss.
The more conservative **50% trading strategy eliminates the risk of a loss**, because **balance costs are equal to spot market prices** and **you can curtail the wind farm to avoid balance costs.**

Forecast Game 1:
Offshore wind power decision making in extreme events

ANALYSIS of Questions – preferred information -

Histogram of participants' preferred information

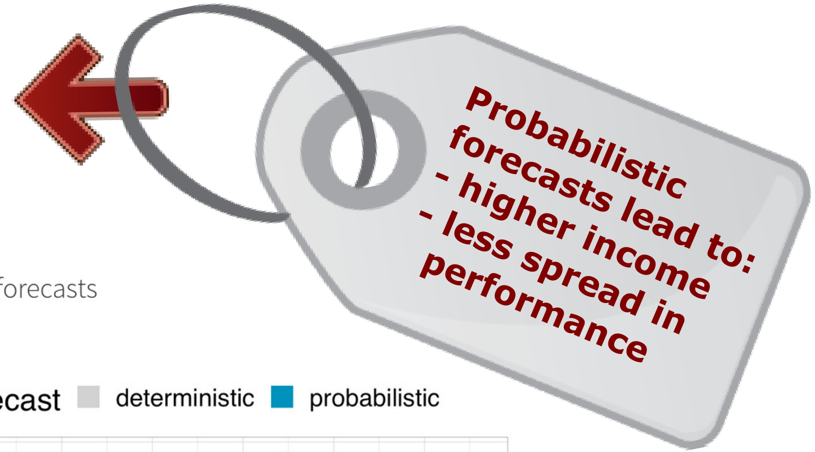
No one preferred to make decisions based on deterministic power forecast alone.



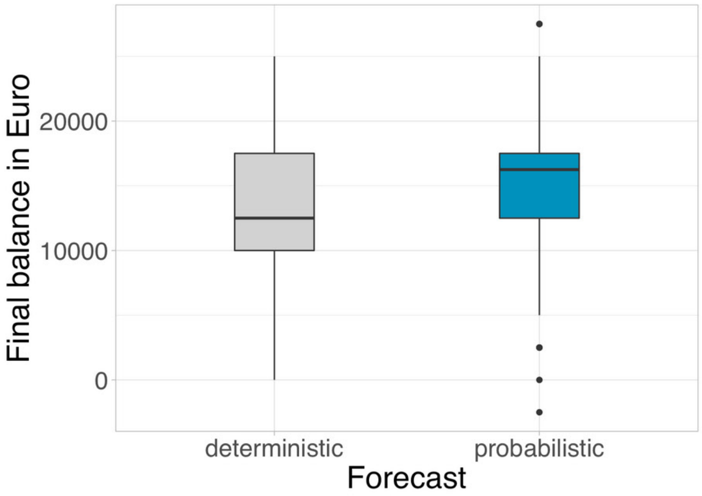
Forecast Game:
Offshore wind power decision making in extreme events

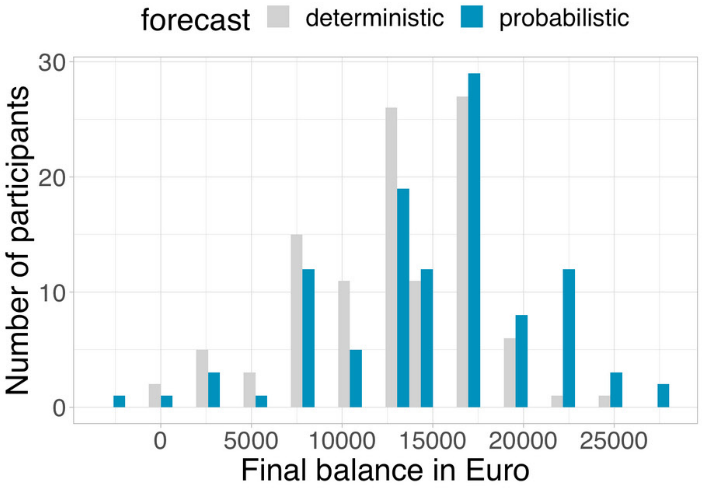
ANALYSIS – final balance -

108 participants:
Best score deterministic: 25.000 EUR
Best score probabilistic: 27.500 EUR



Histogram of participants' final balance based on deterministic vs. probabilistic forecasts





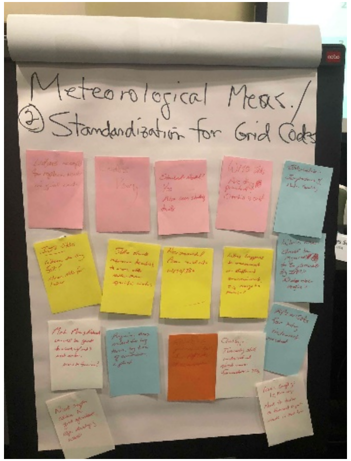
WP3.3: Meteorological Measurements and Instrumentation Standardization for Integration into Grid Codes

Results from 2 Workshops: ICEM 2019 & WIW 2019

Need for Industry Standard ?

→ Need for best practices: BUT too strict standards are worse than non
→ No standards leads to chaotic data management
→ Instrumentation without maintenance: data looses value
→ Maintenance schedules: once, twice per year ?
→ Met instrumentation should be part of the turbine delivery/installation

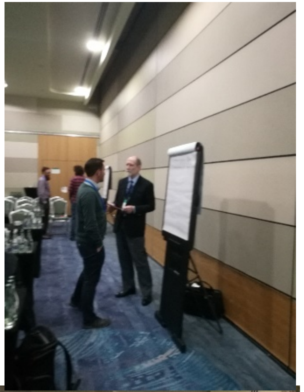
- **Dissemination**
  - No consensus on how to accomplish
  - ENSO-E is a potential body for dissemination
  - Forecasting still undervalued. Need more forecasters in TSOs.
  - Need simple advice to give operators, especially in the developing world



WP3.3: Meteorological Measurements and Instrumentation Standardization for Integration into Grid Codes

Results from 2 Workshops: ICEM 2019 & WIW 2019

- **General Agreement that Standards/RPs are Needed**
  - Grid codes vary from region to region
  - Concern about adopting WMO or similar standards, which may be expensive overkill for grid code purposes
  - Should reference traceability to standards but be instrument agnostic
  - Could suggest required measurements by IPPs at time of commissioning
  - Need education on importance of data quality
  - Need to address site selection for instrumentation
  - Need to tailor reporting interval to forecast model input needs



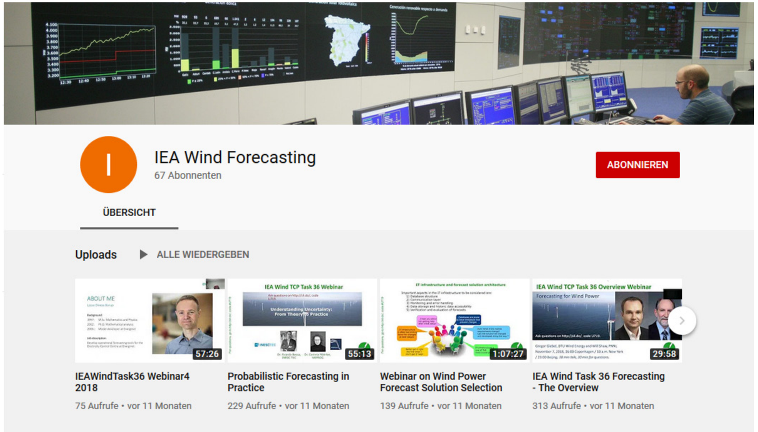
Task 36 Web Presence

Website

www.ieawindforecasting.dk

YouTube Channel

https://www.youtube.com/channel/UCsP1rLoutSXP0ECZKicczXg

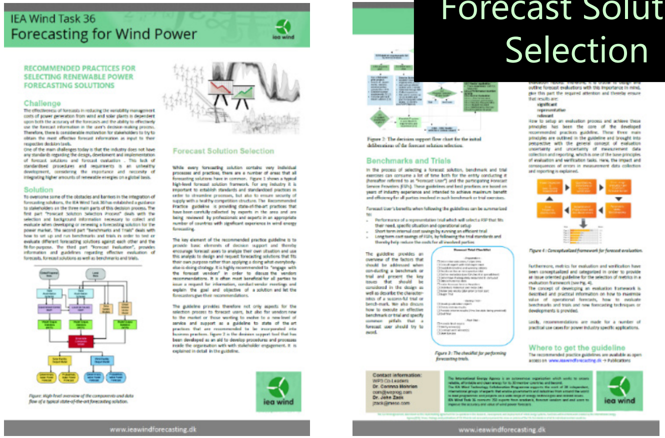


Handouts

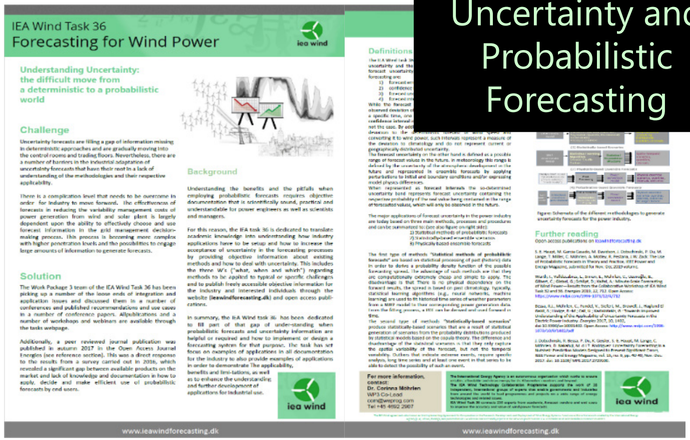
- 2-page handouts: quick overview of major results
- 3 currently available; can be obtained from:

  http://www.ieawindforecasting.dk/publications/posters-og-handouts

Task 36 Overview

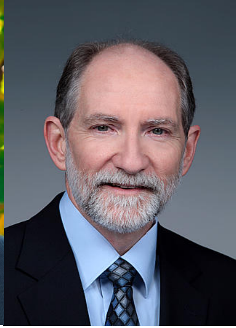


Forecast Solution Selection



Uncertainty and Probabilistic Forecasting

Thank you!



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Richland (WA), USA

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Annex

International Energy Agency History

The IEA was founded in 1974 to help countries co-ordinate a collective response to major disruptions in the supply of oil.

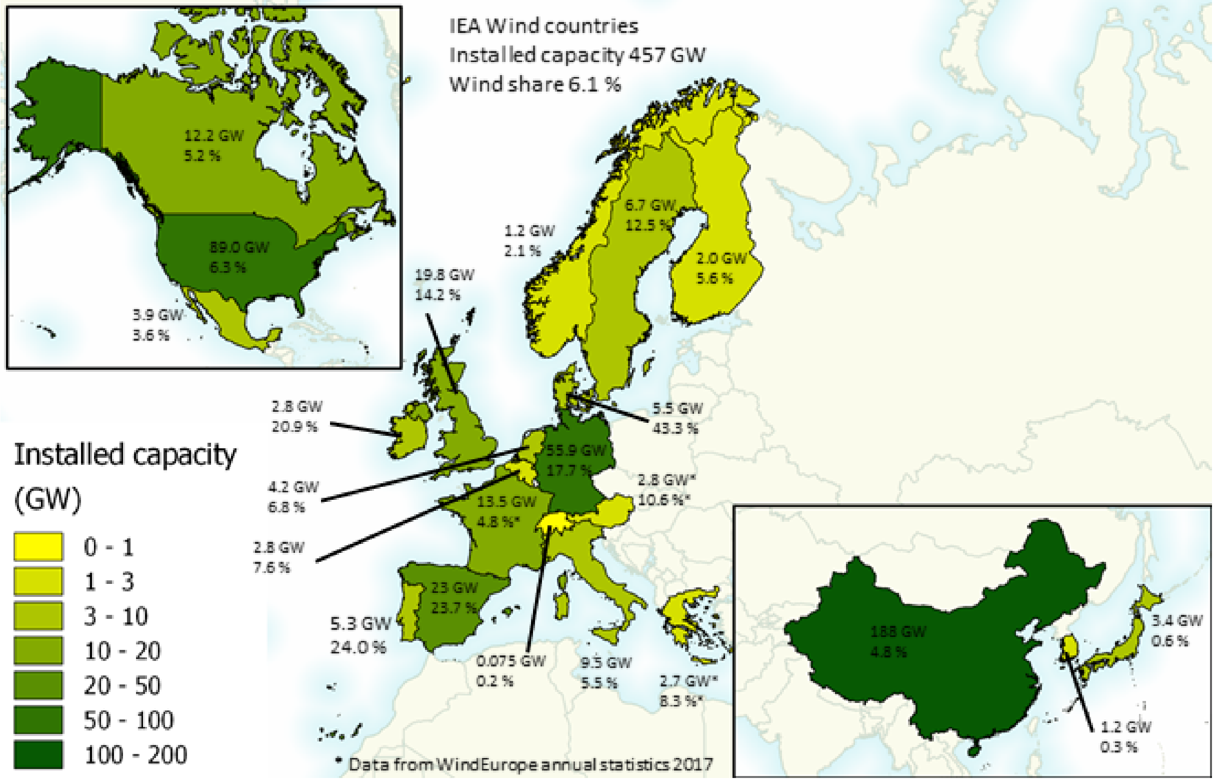
Image source: dpa

Specific Technology Collaboration Programs:

Bioenergy TCP
Concentrated Solar Power (SolarPACES TCP)
Geothermal TCP
Hydrogen TCP
Hydropower TCP
Ocean Energy Systems (OES TCP)
Photovoltaic Power Systems (PVPS TCP)
Solar Heating and Cooling (SHC TCP)
Wind Energy Systems (Wind TCP)

iea Energy Technology Network

See iea.org!



Task 36 members:

AT, CN, DE, DK, ES, FI, FR, IE, PT, SE, UK, US

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Task 11 Base Technology Exchange
Task 19 Wind Energy in Cold Climates
Task 29 Mexnext III: Analysis of Wind Tunnel Measurements and Improvements of Aerodynamic Models
Task 30 Offshore Code Comparison Collaboration, Continued, with Correlation (OC5)
Task 39 Quiet Wind Turbine Technology
Task 40 Downwind Turbines
Task 41 Distributed Energy
Task 42 Wind Turbine Lifetime Extension

See ieawind.org!

Task 31 WAKEBENCH: Benchmarking Wind Farm Flow Models
Task 32 LIDAR: Wind Lidar Systems for Wind Energy Deployment
Task 36 Forecasting for Wind Energy
Task 25 Design and Operation of Power Systems with Large Amounts of Wind Power
Task 27 Small Wind Turbines in High Turbulence Sites
Task 37 Wind Energy Systems Engineering
Task 26 Cost of Wind Energy
Task 28 Social Acceptance of Wind Energy Project
Task 34 Working Together to Resolve the Environmental Effects of Wind Energy (WREN)

Short-term prediction of wind power, quickly explained

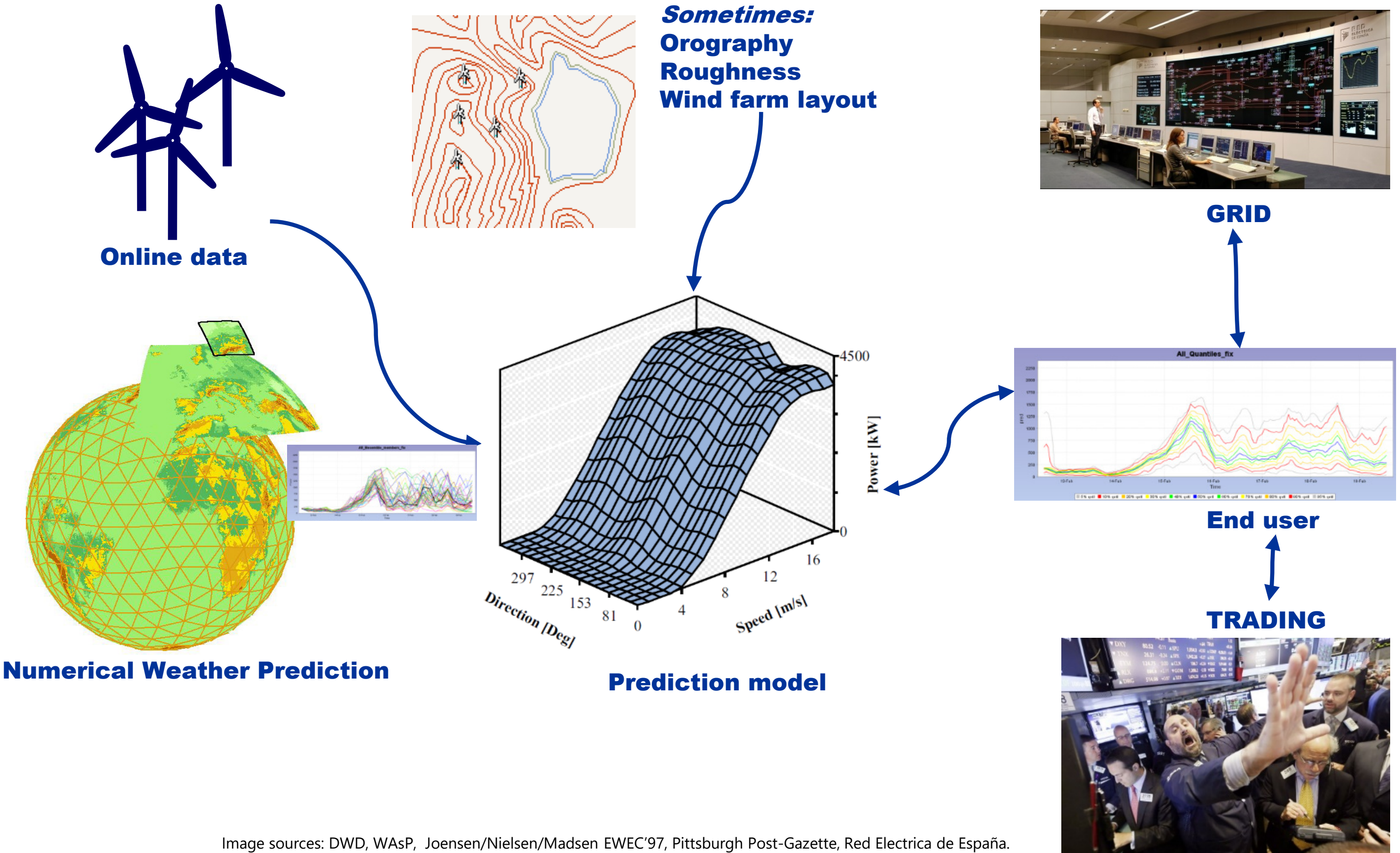
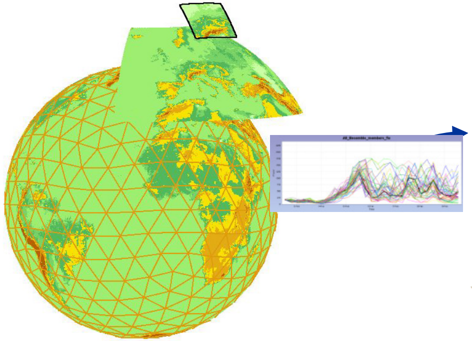
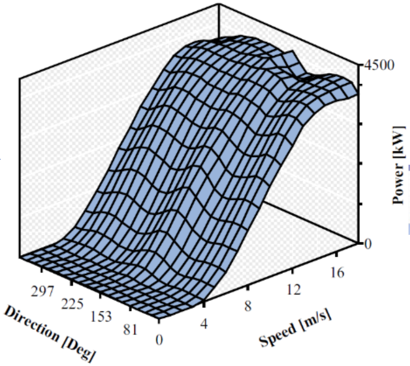


Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Pittsburgh Post-Gazette, Red Electrica de España.



Numerical Weather Prediction

DWD
NOAA
National Weather Service
DMI
ECMWF
Meteo France
China Meteorological Administration
Met Office



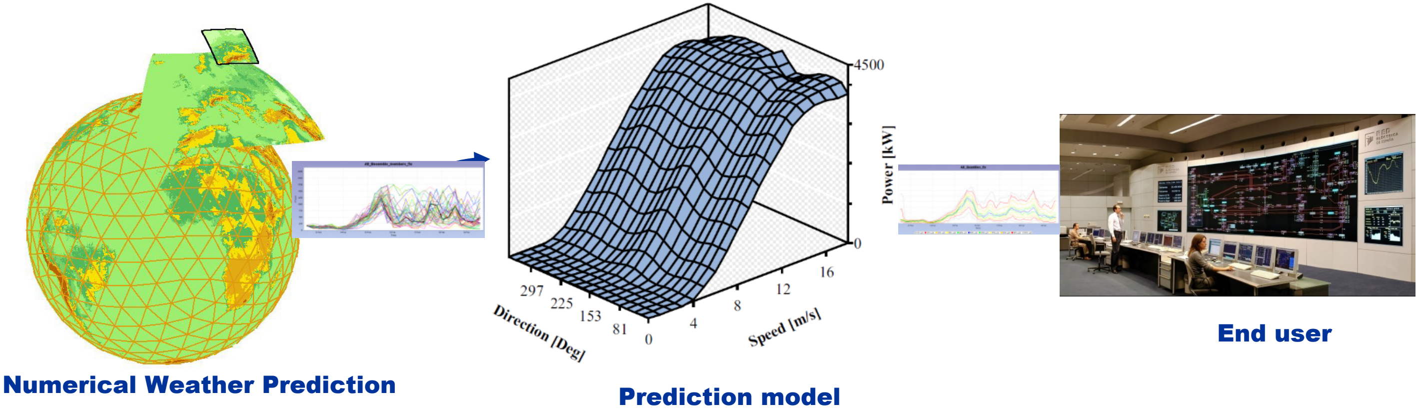
Prediction model

ENFOR
Forecasting and Optimization for the Energy Sector
DNV·GL
WEPROG
energy & meteo systems
ConWX
Fraunhofer IWES
EWC European Weather Consult
NCAR
meteo*swift
VAISALA
4cast

End user

50hertz
ISO new england
engie Green
ercot
amprion
nationalgrid
CNR
California ISO
VATTENFALL
TenneT Taking power further
e·on
ENERGINET/DK
Statoil

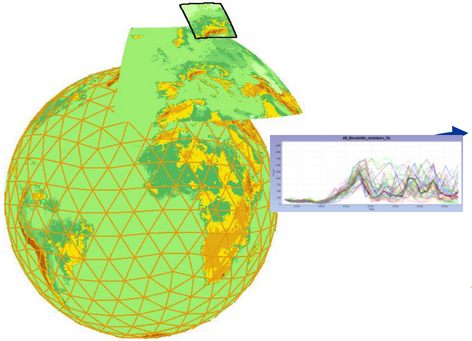
Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.



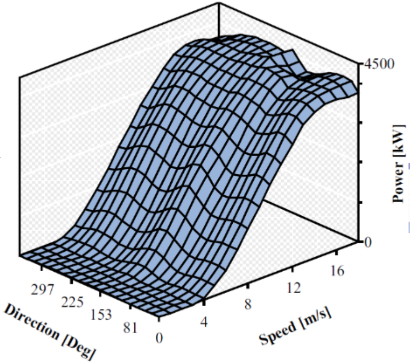
WP1:

- Coordination
- Datasets
- Benchmarks

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.



Numerical Weather Prediction



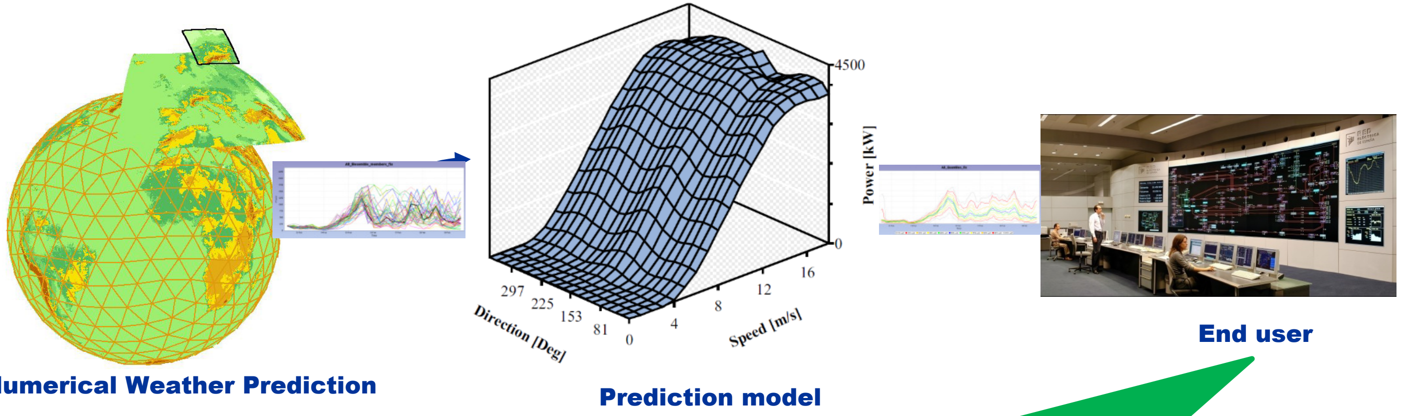
Prediction model

End user

WP2:

Vendor selection
Evaluation protocol
Benchmarks

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.



WP3:

Decision support
Best Practice in Use
Communication

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.

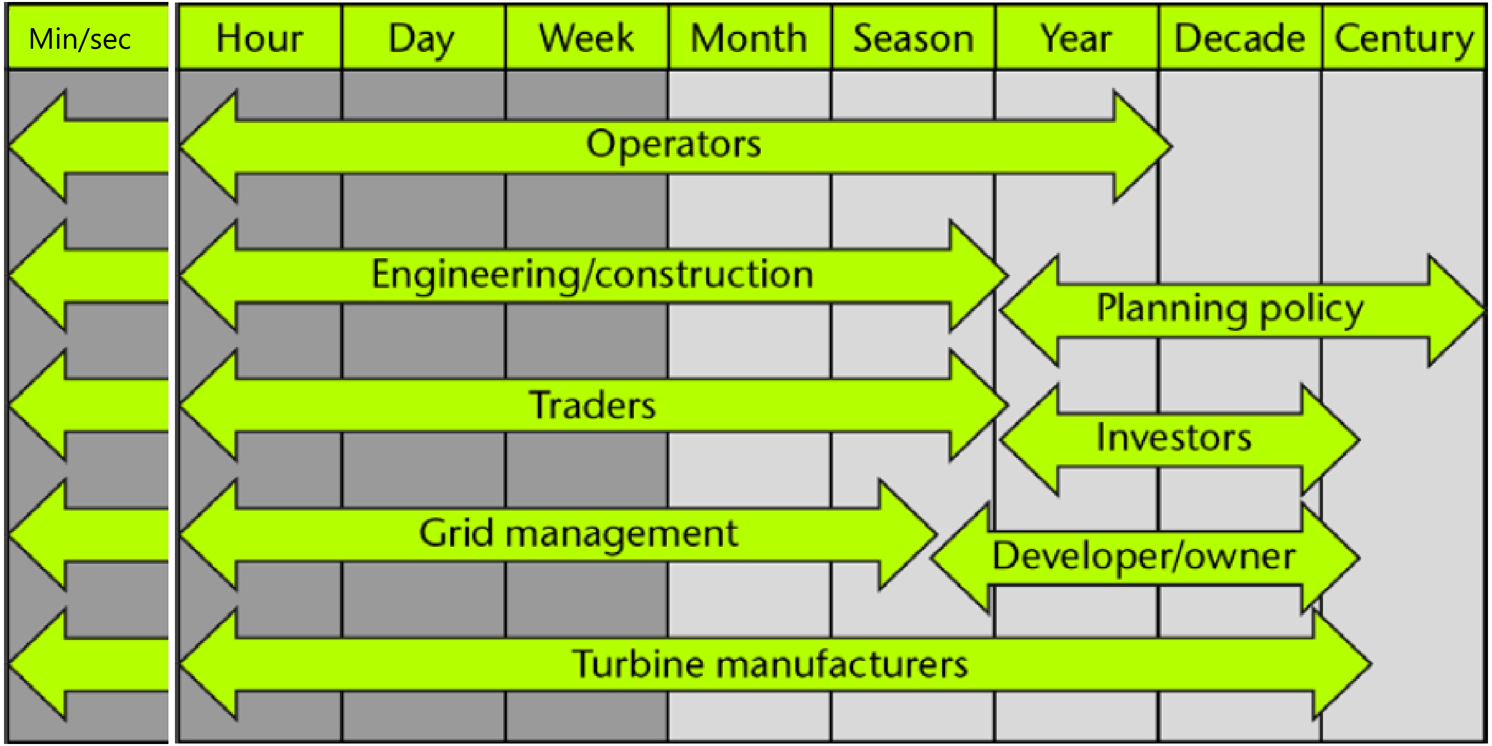
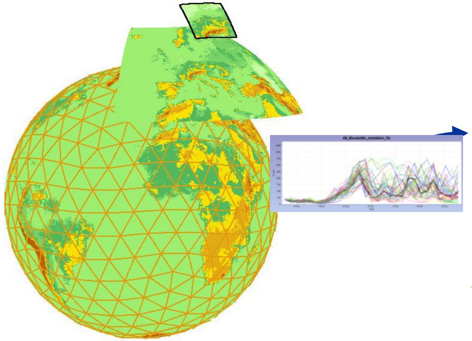


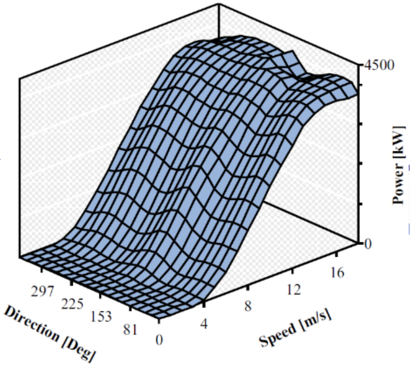
Figure 1: Timescales for the future of wind

Task 36 Phase 2: Work Package Scope

- WP 1: **Global Coordination in Forecast Model Improvement**
  - 1.1 Compile list of available wind data sets suitable for model evaluation
  - 1.2 Annually document field measurement programs & availability of data
  - 1.3 Verify and validate NWP improvements with common data sets
  - 1.4 Work with the NWP centers to include energy forecast metrics in evaluation of model upgrades
- WP 2: **Power and Uncertainty Forecasting**
  - 2.1 Update the IEA Recommended Practice on Forecast Solution Selection
  - 2.2 Uncover uncertainty origins & development through the whole modelling chain
  - 2.3 Set-up and disseminate benchmark test cases and data sets
  - 2.4 Collaborate with IEC on standardisation for forecast vendor-user interaction
- WP 3: **Optimal Use of Forecasting Solutions**
  - 3.1 Use of forecast uncertainties in the business practices
  - 3.2 Review existing/propose new best practices to quantify value of probabilistic forecasts.
  - 3.3 Develop data requirements for real-time forecasting models for use in grid codes



Numerical Weather Prediction



Prediction model

End user

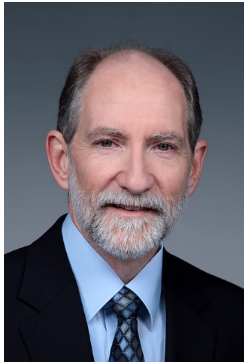
WP1: Coordination Datasets Benchmarks

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.

WP1 Meteorology

Lead:

- Helmut Frank, DWD
- Will Shaw, PNNL



Mission:

To coordinate NWP development for wind speed & power forecasting

WP1 Meteorology

- Task 1.1: Compile list of **available data sets**, especially from tall towers.
- Task 1.2: Creation of annual reports documenting and announcing **field measurement programs** and availability of data.
- Task 1.3: Verify and Validate the improvements through a **common data set** to test model results upon and discuss at IEA Task meetings

WP1 Meteorology Current state

- V&V benchmark defined (US results to be published end of June, benchmark to be published on A2E site)
- Continuously updating the list, and work underway to use the collected data sets for Numerical Weather Prediction

SITE NAME	COORDINATES	ALTITUDE ABOVE MSL	TOWER HEIGHT	URL	CONTACT	DATA POLICY	DATA FORMAT	OBS. PERIOD	OTHER
Cabauw, NL	4.926° E, 51.97° N	-0.7 m	200 m	www.cesar-observatory.nl/index.php	henk.klein.baltink@knmi.nl	Cesar data policy	netCDF	2000-04-01 to previous month	
IJmuiden, NL	3.436° N, 52.848° E	0 m	92 m	www.meteomastijmuiden.nl/en /measurement-campaign/	verhoef@ecn.nl			since 2012	offshore North Sea
Risø, DK	12.088° E, 55.694° N	0 m	125 m	rodeo.dtu.dk/rodeo /ProjectOverview.aspx?&Project=5& Rnd=975820	Allan Vesth	Ask nicely		1995-11-20 -	Data measured since 1958; some months break in 2008.
Østerild, DK	8.88080° E, 57.04888° N	9 m	250 m	rodeo.dtu.dk/rodeo /ProjectOverview.aspx?&Project=17& Rnd=975820	Yoram Eisenberg	Ask nicely		2015-01-28 -	Two 250m masts in 4.3 km distance, both instrumented. Additionally, 7 smaller masts

Minute scale forecasting

- How to use Lidars, Radars or SCADA for very short term forecasts
- 30 sec – 15 min.
- Workshop with Task 32 Lidars at Risø 12/13 June 2018.
- Slides available from workshop website.
- Complete workshop on YouTube.
- Summary paper in Energies journal.

Minute scale forecasting

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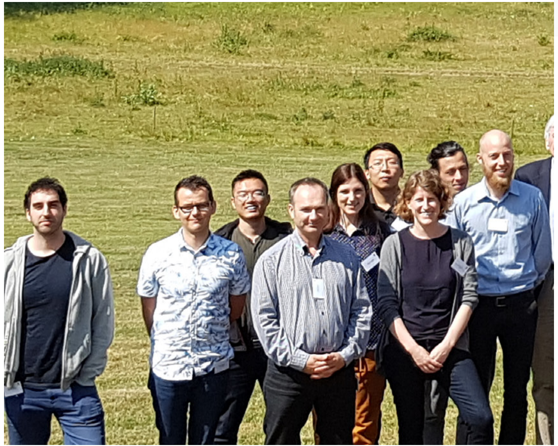

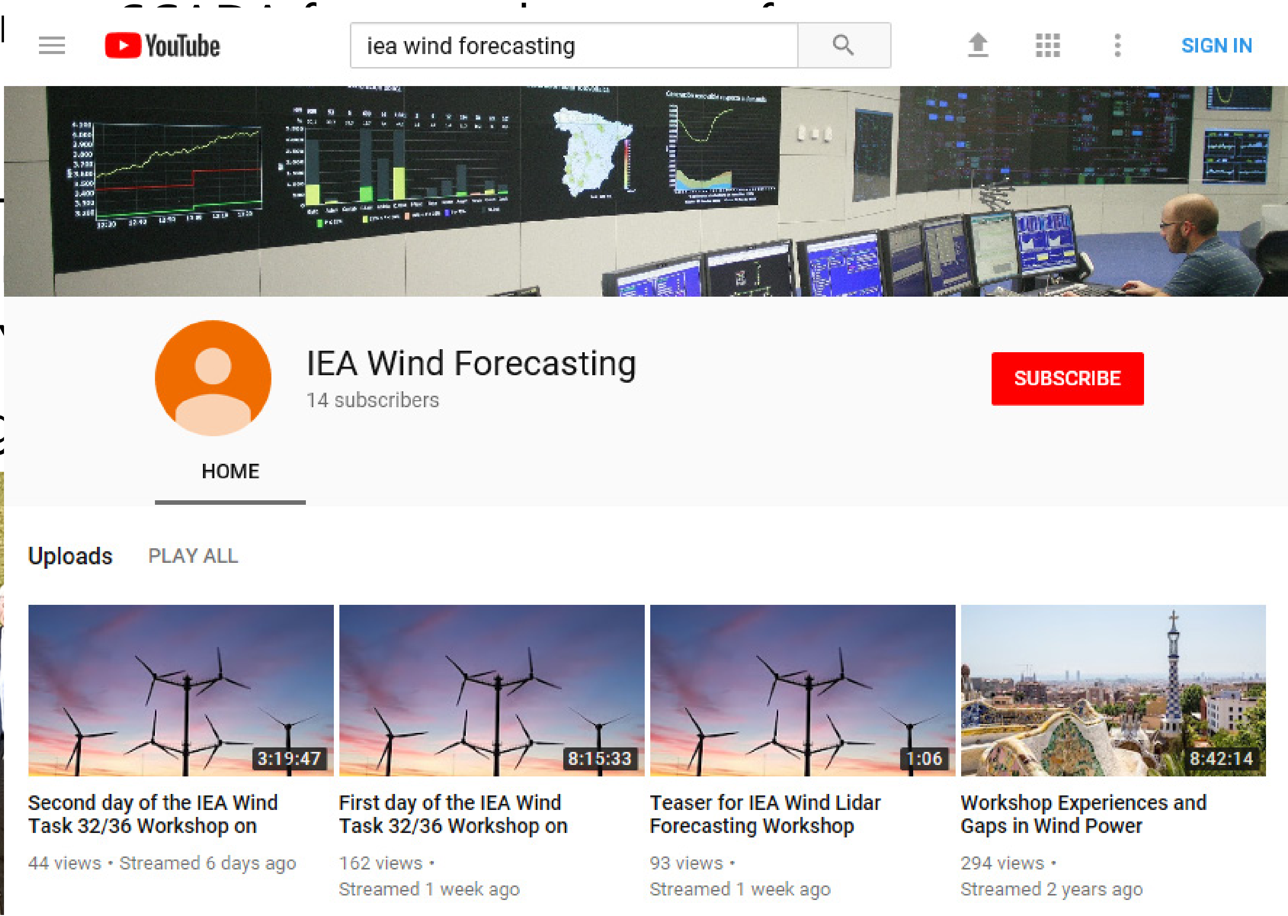

Minute scale forecasting

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energies

MDPI

Article

Minute-Scale Forecasting of Wind Power—Results from the Collaborative Workshop of IEA Wind Task 32 and 36

Ines Würth [1,*], Laura Valldecabres [2], Elliot Simon [3], Corinna Möhrlen [4], Bahri Uzunoğlu [5,6], Ciaran Gilbert [7], Gregor Giebel [3], David Schlipf [8] and Anton Kaifel [9]

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Received: 14 December 2018; Accepted: 14 February 2019; Published: 21 February 2019

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Abstract: The demand for minute-scale forecasts of wind power is continuously increasing with the growing penetration of renewable energy into the power grid, as grid operators need to ensure grid stability in the presence of variable power generation. For this reason, IEA Wind Tasks 32 and 36 together organized a workshop on "Very Short-Term Forecasting of Wind Power" in 2018 to discuss different approaches for the implementation of minute-scale forecasts into the power industry. IEA Wind is an international platform for the research community and industry. Task 32 tries to identify and mitigate barriers to the use of lidars in wind energy applications, while IEA Wind Task 36 focuses on improving the value of wind energy forecasts to the wind energy industry. The workshop identified three applications that need minute-scale forecasts: (1) wind turbine and wind farm control, (2) power grid balancing, (3) energy trading and ancillary services. The forecasting horizons for these applications range from around 1 s for turbine control to 60 min for energy market and grid control applications. The methods that can be applied to generate minute-scale forecasts rely on upstream data from remote sensing devices such as scanning lidars or radars, or are based on point measurements from met masts, turbines or profiling remote sensing devices. Upstream data needs to be propagated with advection models and point measurements can either be used in statistical time series models or assimilated into physical models. All methods have advantages but also shortcomings. The workshop's main conclusions were that there is a need for further investigations into the minute-scale forecasting methods for different use cases, and a cross-disciplinary exchange of different method experts should be established. Additionally, more efforts should be directed towards enhancing quality and reliability of the input measurement data.

Keywords: wind energy; minute-scale forecasting; forecasting horizon; Doppler lidar; Doppler radar; numerical weather prediction models

Energies **2019**, *12*, 712; doi:10.3390/en12040712 www.mdpi.com/journal/energies

Task 1.1 Available Data Sets
Task 1.2 List of Field Campaigns
Task 1.3 Common Test Data
Task 1.4 NWP Forecast Metrics

Task 1.1 Available Data Sets

Meteorological data from tall towers

The following list was compiled by IEA Wind Task 36 Forecasting for Wind Energy.

Another source is **The Tall Tower Dataset** at INDECIS Data portal. This is database of 222 tall towers around the world compiled with a common format (netCDF) and quality controlled. For some towers the latest data is from 2018. See The Tall Tower Dataset Technical Note for a description of the quality control, and a list of the towers in the appendix.

Lead

Helmut Frank
DWD, Deutscher Wetterdienst

SITE NAME	COORDINATES	ALTITUDE ABOVE MSL	TOWER HEIGHT	URL	CONTACT	DATA POLICY	DATA FORMAT	OBS. PERIOD	OTHER
Cabauw, NL	4.926° E, 51.97° N	-0.7 m	200 m	www.cesar-observatory.nl/index.php	marcel.brinkenberg@knmi.nl	Cesar data policy	netCDF	2000-04-01 to previous month	
IJmuiden, NL	3.436° N, 52.848° E	0 m	92 m	www.windopzee.net/en/meteomast-ijmuiden-mmij/	hans.verhoef@tno.nl. Registration for data	Ask here for permission		2012 - 2018	Offshore North Sea
Risø, DK	12.088° E, 55.694° N	0 m	125 m	rodeo.dtu.dk/rodeo/ProjectOverview.aspx?&Project=5&Rnd=975820	Allan Vesth	Ask nicely	xlsx	1995-11-20 -	Data measured since 1958; some months break in 2008.
Østerild, DK	8.88080° E, 57.04888° N	9 m	250 m	rodeo.dtu.dk/rodeo/ProjectOverview.aspx?&Project=179&Rnd=975820	Yoram Eisenberg	Ask nicely	xlsx	2015-01-28 -	Two 250m masts in 4.3 km distance, both instrumented. Additionally, 7 smaller masts up to turbine hub heights.
Taggen, SE	14.519° E, 55.8726° N	0 m	100 m	rodeo.dtu.dk/rodeo/ProjectOverview.aspx?&Project=174&Rnd=758000	Göran Loman			2014-07-29 to 2017-	Offshore. Owned by Vattenfall

IEA WIND TASK 36

iea wind

INFORMATION PORTAL | WORK PACKAGES | PARTNERS | PUBLICATIONS | MEMBER SITE | IEA WIND

WP1 Weather Prediction Improvements | WP2 Benchmarks | WP3 Optimal Use of Forecasting Solutions

Task 1.2 List of Field Campaigns

IEA Wind Task 36 Forecasting for Wind Energy
WP 1 Global Coordination in Forecast Model Improvement

January 10, 2020

Helmut Frank (DWD), Irene Schicker (ZAMG), Will Shaw (PNNL)

Field measurement programs - Introduction

In IEA Wind Task 36 no experiments are made to compare Numerical Weather Prediction (NWP) models with observations. However, there are work packages trying to foster this comparison. Therefore, we compile a list of experiments which are particularly relevant for wind energy forecasting. We try to give a short description of the experiments and some information on the data.

List of major field experiments in different years

2021/2022:

- AWAKEN (USA)

2020:

- FESSTVaL (Germany)

2019:

- NEWA - Alaiz Experiment (ALEX17) (Spain)

2018:

- NEWA - Perdigão Experiment (Portugal)

2017:

- WFIP 2
- NEWA - Ferry Lidar Experiment (Baltic Sea)
- WIPAF (North Sea, Germany)

2016:

- WFIP2 (USA)
- NEWA - The coastal experiment RUNE (Denmark)

Lead

Helmut Frank
DWD, Deutscher Wetterdienst

Co-lead

Will Shaw
Pacific North-West National Laboratory

Long list of experiments, linking to a larger description. Includes older experiments with open data.

List of major field experiments in different years

2021/2022:

- AWAKEN (USA)

2020:

- FESSTVaL (Germany)

2019:

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- NEWA - Ferry Lidar Experiment (Baltic Sea)
- WIPAF (North Sea, Germany)

2016:

- WFIP2 (USA)
- NEWA - The coastal experiment RUNE (Denmark)

- NEWA - Østerild: Flow over heterogeneous roughness (Denmark)
- NEWA - Hornamossen: flow over forested rolling hills (Sweden)
- NEWA - Kassel forested hill experiment (Germany)
- OBLEX-F1 Offshore Boundary-Layer EXperiment at Fino1 (North Sea)
- WIPAFF (North Sea, Germany)

2015:

- WFIP2 (USA)
- OBLEX-F1 Offshore Boundary-Layer EXperiment at Fino1 (North Sea)
- MATERHORN-Fog 2 (USA)

2014:

- ALNAP (Alps)

2013:

- MATERHORN-Spring (USA)

2012 and older:

- MATERHORN-Fall (USA)
- WFIP (USA)

Major field experiments

AWAKEN

The American Wake Experiment (AWAKEN) is a landmark collaborative international wake observation and validation campaign. Wake interactions are among the least understood and most impactful physical interactions in wind plants today, leading to unexpected power losses and increased operations and maintenance costs. The AWAKEN campaign is designed to gather observational data to address the most pressing science questions about wind turbine wake interactions and aerodynamics and to further understand wake behavior and validate wind plant models. Simultaneously, the AWAKEN campaign will also focus on testing of wind farm control strategies that have been shown to increase wind plant power production. Leveraging the expertise and resources of a large body of National Laboratories, academic institutions, and industry partners will lead to improved wind farm layout with greater power production and improved reliability, ultimately leading to lower wind energy costs.

Objectives

Wind power prediction project list

This list shows a large number of (mostly publically funded) research projects in short-term forecasting of wind power. The list is incomplete, as the emphasis was a) on current projects, and b) on projects collected from the Task participants. Even so, the list contains research projects from the last two decades worth 46 M€, with 32 M€ public funding, though not all of this can be attributed to forecasting (e.g. the IRP Wind or RAVE projects).

If you have additions or comments, please send them to the operating agent, Gregor Giebel (grgi /at/ dtu.dk).

Country	Project acronym	Full title	Sponsor	Total / Funded budget	Start - end date	Participants (IEA Task 36 members in bold)
DE	e-TWINS	Verbundvorhaben: e-TWINS ' Ganzheitliche digitale Zwillingstechnologie für das Energiesystem	BMWi (Bundesministerium für Wirtschaft und Energie)	1.96 M€ / 1.96 M€	Jan 2020 - Dec 2022	TU München Windenergie, Hochschule München, **ZSW**, Mesh Engineering
EU	Smart4RES	Next Generation Modelling and Forecasting of Variable Renewable Generation for Large-scale Integration in Energy Systems and Markets	EU Horizon2020	4 M€ / 4 M€	1 Nov 2019 - 30 Apr 2023	**Armines, DTU, INESC TEC, EDP, Meteo-France, emsys, DNV GL,** Whiffle, Dowel, ICCS, HEDNO, DLR
EU	EoCoE II	Energy Oriented Center of Excellence : toward exascale for energy	EU Horizon2020	9.2M€	1.1.2019-31.12.2021	18 teams in 7 countries including **Fraunhofer IEE**
DK	[link]	IEA Wind Task 36 Phase II Danish Consortium	EUDP (national Danish funding)	500k€ / 300k€	1 Jan 2019 - 31 Dec 2021	**DTU, ConWX, ENFOR, DNV, WEPROG, Ea Energianalyse, Energinet**

Wind power prediction project list

This list shows a large number of (mostly publically funded) research projects in short-term forecasting of wind power. The list is incomplete, as the emphasis was a) on current projects, and b) on projects collected from the Task participants. Even so, the list contains research projects from the last two decades worth 46 M€, with 32 M€ public funding, though not all of this can be attributed to forecasting (e.g. the IRP Wind or RAVE projects).

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		impact on the Danish power system	EUDP)			**Vattenfall**
NO	NowWind	Nowcasting for wind energy production - an integrated modelling approach	The Research Council of Norway (ENERGIX)	12 MNOK / 6.3 MNOK (1.3 / 0.7 M€)	2016 - 2019	**MET Norway, Windsim AS, Vestas Wind Systems AS**, TrønderEnergi AS, **Kjeller Vindteknikk** AS
FR	FOREWER	**Modélisation, prévision et évaluation des risques pour la production d'énergie éolienne**	Agence Nationale de la Recherche (French)	2160 k€ / 481 k€	1 Oct 2014 - 31 Mar 2019	Université Paris 7, **ENGIE Green**, Ecole Polytechnique, EDF, RTE, CNRS
FR	meteo*swift	Development of a short-term wind power forecasting tool based on adaptive multi-agent systems and ensemble weather forecasts	FEDER EU funding & Occitania French region	~1 M€ / ~500 k€	Mar 2016 - Mar 2018	**meteo*swift**, National Weather Research Center (part of Météo-France), Toulouse Computer Science Research Institute
DK	[link]	IEA Wind Task 36 Forecasting Danish Consortium	EUDP (nationally Danish)	2.72 MDKK / 1.83 MDKK	Jan 2016 - Dec 2018	**DTU Wind Energy, DTU Elektro, DTU Compute, DMI, ENFOR, DNV GL, WEPROG, Vestas, Energinet.dk**
US		IEA Task on Development & Use of	Department of Energy USA	$22,732	Sep 2016 - Sep 2017	**NREL**
US	WFIP 2 (alternate link)	Second Wind Forecast Improvement Project	U.S. Department of Energy	$17M USD / $17M USD	1 Oct 2015 - 30 Sep 2018	**Vaisala, NOAA/ESRL, NOAA/ARL, NOAA/NWS,** Argonne National Laboratory, Lawrence Livermore National Laboratory, **NREL, PNNL**
EU	EoCoE	Energy oriented Centre of Excellence	EU Horizon2020	~5.5 M€ / ~1.4 M€	Oct 2015 – Sep 2018	21 teams in 8 countries, lead by Maison de la Simulation, including **Fraunhofer IWES**
EU	IRP Wind	Integrated EU R&D efforts on wind energy	EU 7th Framework Programme (Project ID: 609795)	~ 10 M€ / ~10 M€	Mar 2014 – Feb 2018	24 European teams (participants of the European Energy Research Alliance (EERA) Joint Programme on Wind Energy) lead by **DTU Wind Energy**
DE	PriME	Innovative probabilistic methods for energy system technology	German Federal Ministry of Education and Research (BMBF)	~1 M€ / ~1 M€	Jan 2015 – Dec 2017	University Kassel, **FH IWES**, EnerginetDK, Netze BW
FR/DK	HD-RESforecast	High-dimensional dynamical models for improving renewable energy forecasting at distributed locations	EDF	116 k€ / 65 k€	Nov 2015 -	**DTU Elektro**, EDF
DE	VORKAST	Optimisation of design and operational management for hybrid power plants and energy storage technologies by means of wind and PV power nowcasting (Optimierung der Auslegung und Betriebsführung	Federal Ministry for Economics and Technology	1 M€ / 1 M€	1 Sep 2014 – 31 Oct 2017	ZSW - Center for Solar Energy and Hydrogen Research Baden-Württemberg (Project lead) SWE – Stuttgart Wind Energy @ Institute of Aircraft Design, University of Stuttgart
DE	SMART GRID SOLAR		Bavarian ministry for economy, EU infrastructure fund "Investments for the future"	10 M€ / 6.3 M€	2012 - 2018	Bavarian Center for Applied Energy Research (ZAE), 3 Fraunhofer institutes, 9 other partners and **WEPROG**
PT	P1	Renewable Energy Dispatch Tools	China Electric Power Research Institute (CEPRI); State Grid Corporation of China (SGCC)	2 M€ / -	1 Jul 2013 - 31 Dec 2016	R&D NESTER (PT), **REN** (PT), **CEPRI** (CN)
DK	X-WiWa	Extreme winds and waves for offshore turbines	ForskEL (PSO)	5.96 MDKK / 5.4 MDKK	1 Jun 2013 - 2017	**DTU Wind Energy**, DHI, **Uni Research,** Bergen University
DE	EWeLiNE	Erstellung innovativer Wetter- und Leistungsprognosemodelle für die Netzintegration wetterabhängiger Energieträger	Bundesministerium für Wirtschaft und Energie	7.06 M€ / 6.5 M€	Dec 2012 - Feb 2017	**Fraunhofer IWES, DWD,** Amprion, TenneT, 50Hertz
DE	PerduS	Photovoltaikertragsreduktion durch Saharastaub	BMWi (Bundesministerium für Wirtschaft und Energie)	962 k€ / 962 k€	Nov 2012 - Feb 2017	**Deutscher Wetterdienst,** KIT, meteocontrol
EU	SafeWind	Multi-scale data assimilation, advanced wind modeling and forecasting with emphasis to extreme weather situations for a integration	EU 7th Framework Programme (FP7-ENERGY, Project ID: 213740)	5.6 M€ / 3.98 M€	1 Sep 2008 - 31 Aug 2012	**Armines, DTU, Risø, Uni Oldenburg, ENFOR, Overspeed, CENER, Energinet.dk** and 13 other partners
DK	DEWEPS	Development and Evaluation of a new wind profile theory with an Ensemble Prediction System	Danish PSO Fund	480 k€ / 180 k€	1 Apr 2009 - 31 Dec 2011	**WEPROG**
EU	ANEMOS.plus	**Advanced Tools for the Management of Electricity Grids with Large-Scale Wind Generation**	EU 6th Framework Programme (Project ID: 38692)	5.7 M€ / 2.6 M€	1 Jan 2008 - 30 Jun 2011	**Armines, DTU, Risø, ENFOR, Overspeed, CENER, INESC,** and 14 other partners
DE	RAVE	Research at Alpha Ventus - Grid Integration of offshore wind farms	**BMU, German ministry for the Environment**	5 M€ (60-80% funded)	2008 - 2011	**Fraunhofer IWES, Forwind - University Oldenburg, Deutscher Wetterdienst, WEPROG**
DK	HREnsembleHR	**High-resolution Ensemble for Horns Reef**	**Danish PSO Fund (Contract No. 2006-1-6387)**	700 k€ / 400 k€	1 Apr 2006 - 31 Dec 2009	**WEPROG, DTU IMM, DTU Risø, Fraunhofer IWES, DONG Energy, Vattenfall**
EU	POW'WOW	Prediction of Waves, Wakes and Offshore Wind	EU 6th Framework Programme (Project ID 19898)	1.05 M€ / 1.05 M€	1 Oct 2005 - 30 Mar 2009	**Risø, DTU, Armines, CENER, Uni Oldenburg, Fraunhofer IWES**, and 8 other partners including UFPE (BR)
EU	ANEMOS	Development of a next generation wind resource forecasting system for the large-scale integration of onshore and offshore wind farms	EU 5th Framework Programme (Project ID: ENK5-CT-2002-00665)	4.3 M€ / 2.5 M€	1 Oct 2002 - 30 Sep 2006	**Armines, DTU, Uni Oldenburg, CENER, IASA,** and 16 others from TSOs to meteorologists

Country	Project acronym	Full title	Sponsor	Total / Funded budget	Start - end date	Participants
E	SMART GRID SOLAR		Bavarian ministry for economy, EU infrastructure fund "Investments for the future"	10 M€ / 6.3 M€	2012 - 2018	Bavarian Center for Applied Energy Research (ZAE), 3 Fraunhofer institutes, 9 other partners and **WEPROG**
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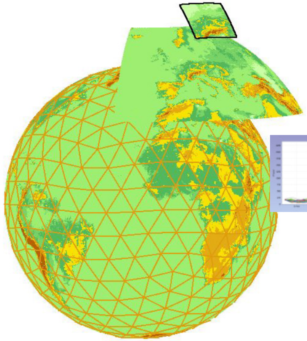
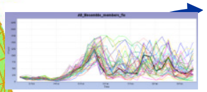
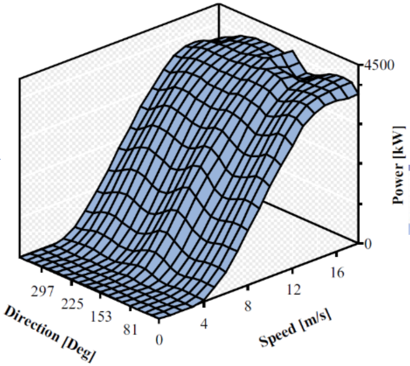
E	EWeLiNE	Erstellung innovativer Wetter- und Leistungsprognosemodelle für die Netzintegration wetterabhängiger Energieträger	Bundesministerium für Wirtschaft und Energie	7.06 M€ / 6.5 M€	Dec 2012 - Feb 2017	**Fraunhofer IWES, DWD,** Amprion, TenneT, 50Hertz
DE	PerduS	Photovoltaikertragsreduktion	BMWi	962 k€ / 962 k€	Nov 2012 - Feb	**Deutscher**

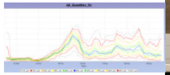




Numerical Weather Prediction



Prediction model



End user

WP2:

Vendor selection
Evaluation protocol
Benchmarks

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.

WP2 Benchmarks

Lead:
Caroline Draxl, NREL
John Zack, UL
Pierre Pinson, DTU Elektro

f in

Task 2.3 Test Cases

Set-up and dissemination of benchmark test cases and data sets.

-

  Aim: Set-up and dissemination of benchmarks.
- **Partners:** DTU Elektro, DTU Wind Energy, EDF, INESC TEC, Smartwatt, Prewind, PNNL.

NAME	TYPE OF DATA	AREA	PERIOD	TEMPORAL RESOLUTION
RE-Europe	Simulated aggregated generation and +1 to +91 hour forecasts for 1494 European regions based on ECMWF and COSMO analysis and ECMWF forecast data	Europe	2012-2014	1 hour
NREL WIND Toolkit	Simulated generation and 1, 4, 6, and 24-hour wind and power forecasts for 126000 US sites based on WRF	US	2007-2013	5 min
NREL Western and Eastern Wind Integration data sets	Simulated generation for 1326 (Eastern) + 32043 (Western) US sites based on MASS and WRF. For Eastern data set also 4 hour, 6 hour and day ahead forecasts	US	2004-2006	10 min
GEFCom 2012	Observed generation and +1 to +48 hour ECMWF wind forecasts for 7 wind farms	unknown	2009-2012	1 hour
GEFCom 2014	Observed generation and +1 to +48 hour ECMWF wind forecasts for 7 wind farms	unknown	2009-2012	1 hour
AEMO	Generation data from various Australian wind farms	Australia	2005-	5 min
La Haute Borne wind farm data	Many SCADA data from the 4 turbines of the La Haute Borne wind farm, ENGIE's first open data wind farm.	Southwest of Nancy, France	2009-	10 min

Co-lead

Pierre Pinson
Professor
DTU Electrical Engineering
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Additional information:

RE-Europe:
Full data set can be downloaded as zip-file. Generation signals and forecasts and meta data on location and aggregation are stored in csv-files. Additional to wind power data the data set includes solar generation and power load data. More information can be found on https://zenodo.org/record/35177#.WqmNAzclFmB. Data policy: Creative Commons Attribution-NonCommercial 4.0.

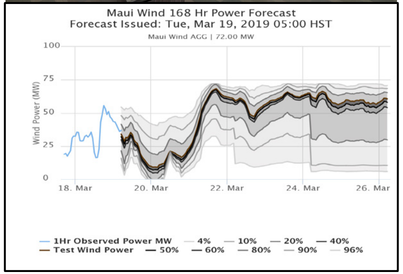
NREL WIND Toolkit:
Information and download links can be found on https://www.nrel.gov/grid/wind-integration-data.html. Data can be downloaded via the NREL Wind Prospector

Work Package 2.1:
Recommended Practice for Optimal Forecast Solution Selection

Slides by John Zack and Corinna Möhrlen

The Problem and an Approach for a Solution

- **Documented Benefits:**
  - Use of forecasts can lower variable generation integration costs while maintaining the required high system reliability
- **Problem:**
  - A substantial amount of value is not realized due to the **use of non-optimal forecast solutions by users**
    - Wrong forecast performance objective(s)
    - Poorly designed and executed benchmarks/trials
    - Use of non-optimal evaluation metrics
- **Potential Mitigation:**
  - IEA Wind Task 36 – Work Package 2 experts formulated a set of "best practices" for selecting and running wind forecasting solutions



iea wind

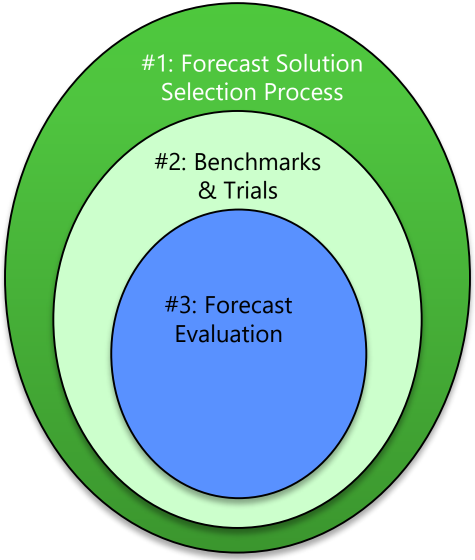
Overview of IEA-WIND Recommended Practice for the Selection of Wind Power Forecasting Solutions (WP 2.1)

Target: Compile guidance for the implementation of renewable energy forecasting into system operation

Approach: Develop a set of 3 documents that specify IEA Wind Recommended Practices for:

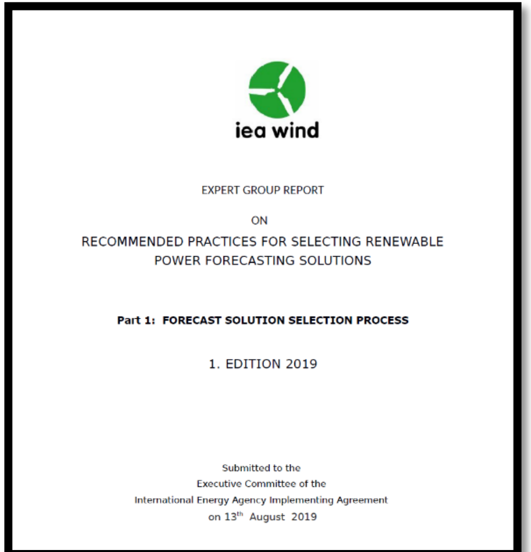
1. **Forecast Solution Selection Process**
2. **Design and Execution of Benchmarks and Trials**
3. **Evaluation of Forecasts and Forecast Solutions**

Current Status: Released



- **Available Online: http://www.ieawindforecasting.dk/publications/recommendedpractice**

IEA Best Practice Recommendations for the Selection of a Wind Forecasting Solution: Set of 3 Documents



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EXPERT GROUP REPORT

ON

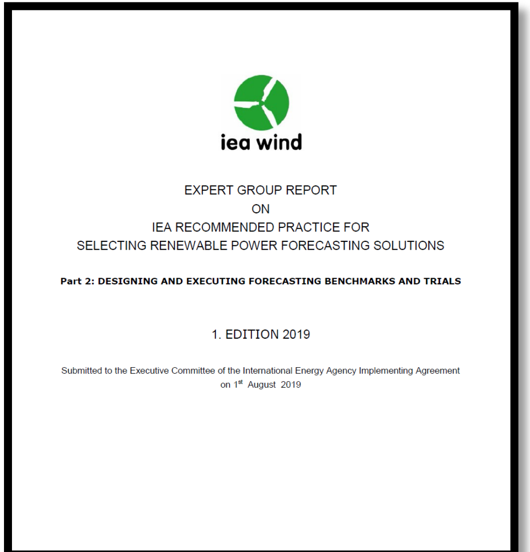
RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 1: FORECAST SOLUTION SELECTION PROCESS

1. EDITION 2019

Submitted to the
Executive Committee of the
International Energy Agency Implementing Agreement
on 13th August 2019

- Part 1: Selection of an Optimal Forecast Solution



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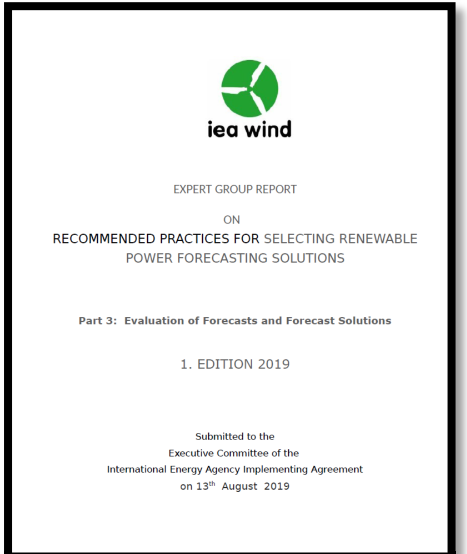
EXPERT GROUP REPORT
ON
IEA RECOMMENDED PRACTICE FOR
SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 2: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS

1. EDITION 2019

Submitted to the Executive Committee of the International Energy Agency Implementing Agreement
on 1st August 2019

- Part 2: Design and Execution of Benchmarks and Trials



iea wind

EXPERT GROUP REPORT

ON

RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 3: Evaluation of Forecasts and Forecast Solutions

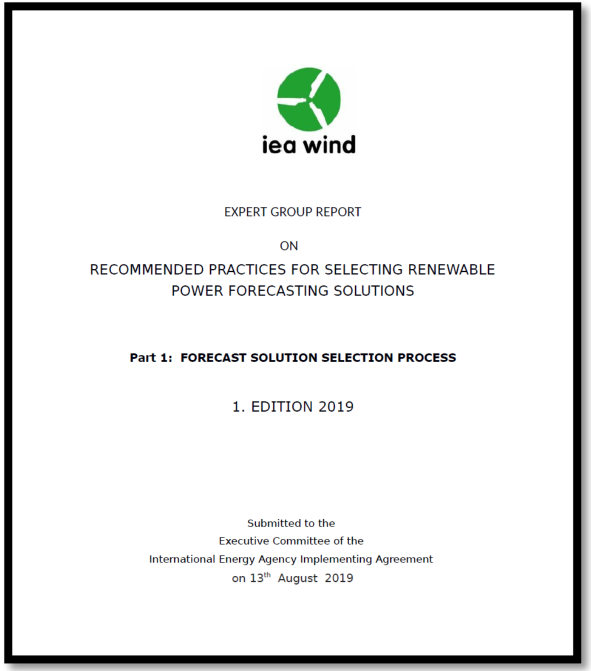
1. EDITION 2019

Submitted to the
Executive Committee of the
International Energy Agency Implementing Agreement
on 13th August 2019

- Part 3: Evaluation of Forecasts and Forecast Solutions

Part 1: Forecast Solution Selection Process:

- **Key Concept**: the "best" practical forecast solution process for an application depends on the user's access to knowledge, labor resources and time
  - Conducting a performance trial may not profile useful guidance if not well designed and executed
  - Alternative approaches to trials may be more effective
- **Key Guidance**:
  - Decision Support Tool: guidance to determine the best approach for a specific situation
  - Check lists of information to gather for trials, RFP, RFI



iea wind

EXPERT GROUP REPORT

ON

RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 1: FORECAST SOLUTION SELECTION PROCESS

1. EDITION 2019

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Executive Committee of the
International Energy Agency Implementing Agreement
on 13th August 2019

IEA Task 36 WP2.1

FORECAST SOLUTION SELECTION AND TRIAL/BENCHMARK EXECU

- **Content Examples:**
  - Decision Support Tool to find best path for appropriate solution
  - Summary trial/benchmark checklist for all end-users
  - Appendices with
    - meta-, historical-, and real time-data details to make communication more efficient
    - Forecast file format sample
    - Questions to ask in RFI/RFP
  - Detailed steps during the three main phases of a trial: preparation, during, and post-trial

Forecast Trial Checklist

--Preparation--

- ☐ Determine outcomes / objectives
- ☐ Consult expert with trial experience
- ☐ Establish timeline and winning criteria
- ☐ Decide on live or retrospective trial
- ☐ Gather metadata (use IEA checklist spreadsheet)
- ☐ Determine if adequately resourced to carry out
- ☐ Obtain historical data
- ☐ Invite Forecast Service Providers
- ☐ Distribute historical and meta-data
- ☐ Allow two weeks Q&A prior to trail start
- ☐ Begin Trial

--During Trial--

- ☐ Develop validation report
- ☐ Check interim results
- ☐ Provide interim results (if no live data being provided)
- ☐ End Trial

--Post Trial--

- ☐ Provide final results
- ☐ Notify winner(s)
- ☐ Contract with winner(s)
- ☐ Start Service

	A	B	C
1	Wind Power Forecast Trial Checklist		
2			
3	Purpose: To efficiently set up site-specific wind power forecast, this checklist should be filled out as best as it could with available informaiton. This will expedite forecast configuration and save back and forth communication time. Please note the comments in the corner of the cells.		
4			
5	QUESTIONS		ANSWERS
6	**Metadata Checklist:**		
7	Name(s) of sites as needed in datafile:		*Acme Wind Farm*
8	Latitude and longitude coordinates of sites? Attaching or copying the turbine as-built locations to another worksheet will be sufficient here.		*42.3523, -121.3282*
9	Nameplate capacity of each site:		*62.5 MW*
10	Will a web tool be needed?		*Yes*
11	Turbine make/model/rating:		*GE:GE2.5-100*
12	Number of turbines:		*25*
13	Hub height of turbines?		*95 meters*
14	Please provide a suitable plant power curve		*attached*
15			
16	**Value of forecast questions:**		
17	Which variables will be forecasted and validated?		*Power (MW)*
18	Which forecast horizon(s) are being verified?		*24-48 hours*
19	Which metrics are being used to gage performance?		*RMSE*
20	If head-to-head trial competition, what are the criteria for determining winning forecast provider?		*Lowest RMSE and price*

WIND | Sample Forecast File

Key Elements of Recommended Practices for Forecast Solution Selection

- Selection/update of forecasting solutions in which **Quality, Reliability and Price** are in perfect harmony is usually a complex task
- Forecast IT infrastructure and solution architecture need careful considerations

→provides decision support for basic elements common to all forecast solutions

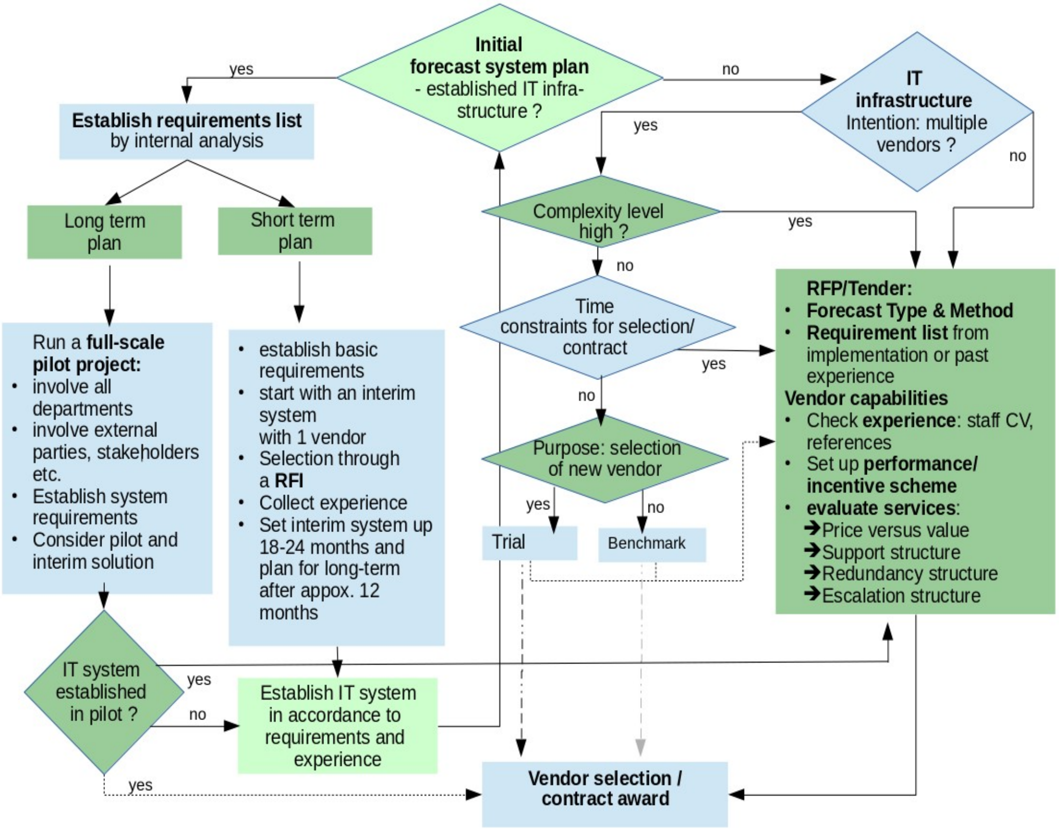
→encourages end-users to analyze their own situation

→encourages users to request a forecasting solution that fits their own purposes

→ discourages to just "do what everybody else is doing"

→ discourages seeking a simple or cheap solution if the application is complex

Decision Support Tool for the Process of Selecting a Forecasting Solution

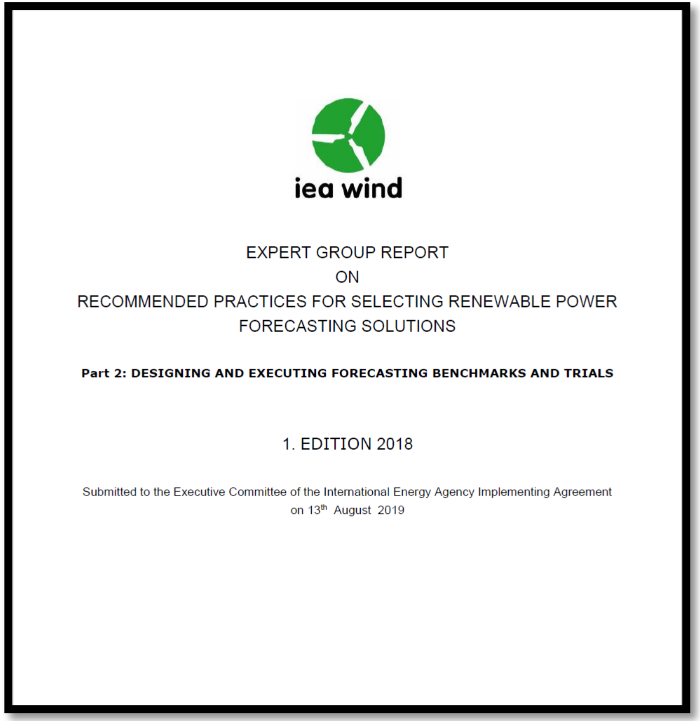


- Provides guidance and practical examples for:
  - the formulation of a process to select an optimal forecasting solution
  - analysis and formulation of forecasting requirements
  - assessing vendor capabilities with and without trials

Part 2: Designing and Executing Forecasting Benchmarks and Trials

- **Key Concept**: a benchmark or trial must be carefully designed, executed and evaluated in order to produce meaningful information that can be used for effective decision-making
  - Many decisions are based on "noise" (random results) produced by benchmarks/trials

- **Key Guidance**:
  - Best practices for the design, execution and evaluation of trial/benchmarks
  - Examples of "pitfalls to avoid"


iea wind

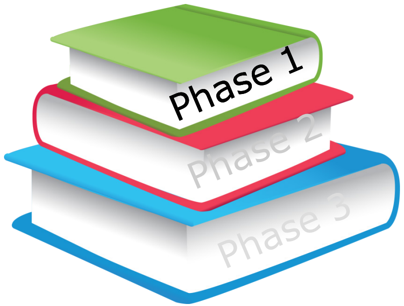
EXPERT GROUP REPORT
ON
RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 2: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS

1. EDITION 2018

Submitted to the Executive Committee of the International Energy Agency Implementing Agreement
on 13th August 2019

The 3 Phases of a Benchmarking Process: #1



Preparation Phase:
determining the scope and focus of the performance evaluation

Forecast horizons (look-ahead time periods)

Available historical data

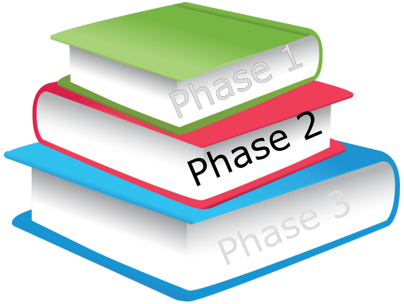
Appropriate length of benchmark

Are conditions during benchmark **representative?**

Meaningful evaluation metrics

Think of what factors are most important as in any big or long-term purchase (e.g. home, car, forecasting system)?

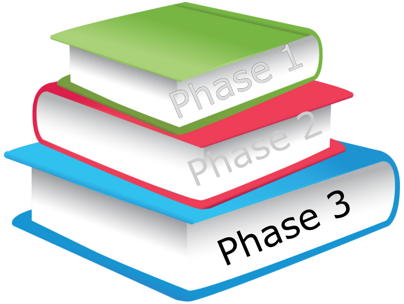
The 3 Phases of a Benchmarking Process: #2



Execution Phase:
ensuring a fair and representative process

- Data monitoring (forecasts and observations)
- For fairness and transparency: test accuracy and delivery performance.
- Monitor forecast receipt (reliability)
- Sample should be normalized (all forecasters evaluated for same period & locations)
- Develop and refine the evaluation scripts

The 3 Phases of a Benchmarking Process: #3



Analysis Phase:
compiling a comprehensive and relevant assessment

- **Critical Evaluation Criteria:**
  - Application-relevant accuracy of the forecasts
  - Performance in the timely delivery of forecasts
  - Ease of working with the forecast provider

Examples of Benchmarking Pitfalls to Avoid

- **Poor communication with forecast providers**
  - All providers not provided with the same set of information
  - Incumbent providers having an information advantage by default
- **Unreliable comparisons**
  - Forecasts for different time periods are compared (evaluated)
  - Forecasts for different facilities/portfolios are compared (evaluated)
- ***Bad design***
  - Short trials in unrepresentative periods (e.g. 1 month in a low wind season)
  - No on-site data given to forecast providers
  - Intra-day forecasts made from once-a-day target-site data update
- ***Details missing or not communicated to providers***
  - No documentation of daylight savings time changes in data files
  - No specification of whether data time stamp represents interval beginning or ending
  - No documentation of plant capacity changes in historical data or trial period
  - Curtailment and maintenance outages not provided
- ***Opportunities for "cheating" not eliminated***
  - No penalty for missing forecasts (possible no submission in difficult situations)
  - Forecast delivery times not enforced (could submit later forecasts)

Part 3: Evaluation of Forecasts and Forecast Solutions

- **Key Concept**: all forecast performance evaluations have a degree of uncertainty that is a composite from a number of factors
  - Management of evaluation uncertainty should be a priority in order to maximize signal/noise
  - Poor management of uncertainty may result in evaluation information being dominated by noise

- **Key Guidance**:
  - Three key attributes of an evaluation process
  - Factors and issues associated with each attribute
  - Approaches to minimize evaluation uncertainty

iea wind

EXPERT GROUP REPORT

ON

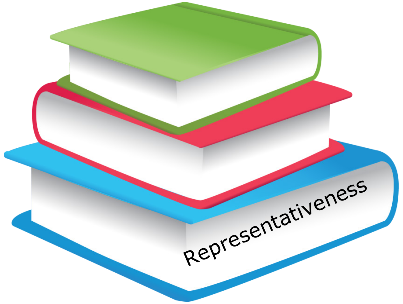
RECOMMENDED PRACTICES FOR SELECTING RENEWABLE POWER FORECASTING SOLUTIONS

Part 3: Evaluation of Forecasts and Forecast Solutions

1. EDITION 2018

To be Submitted to the
Executive Committee of the
International Energy Agency Implementing Agreement
on 1st March 2019

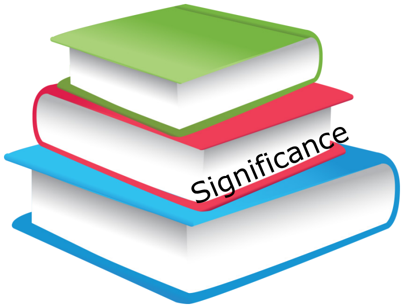
Three Critical Factors to Achieve a Meaningful Trial: #1



Representativeness: relationship between the results of a forecast performance evaluation and the performance that is ultimately obtained in the operational use of a forecast solution

- Statistically meaningful evaluation sample size and composition
- High quality data from the forecast target sites
- Formulation and enforcement of rules governing the submission of forecasts (“fairness”)
- Availability of a complete and consistent set of evaluation procedure information to all evaluation participants (“transparency”)

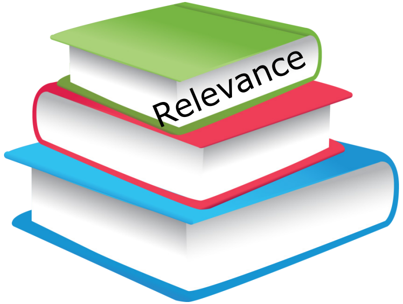
Three Critical Factors to Achieve a Meaningful Trial: #2



Significance: ability to differentiate between performance differences that are due to noise in the evaluation process and those that are due to meaningful differences in skill among forecast solutions

- Minimize noise in the evaluation sample (i.e. lower the uncertainty)
- Quantify the uncertainty in performance metrics
- Consider performance uncertainty bands when evaluating performance differences among candidate solutions

Three Critical Factors to Achieve a Meaningful Trial: #3

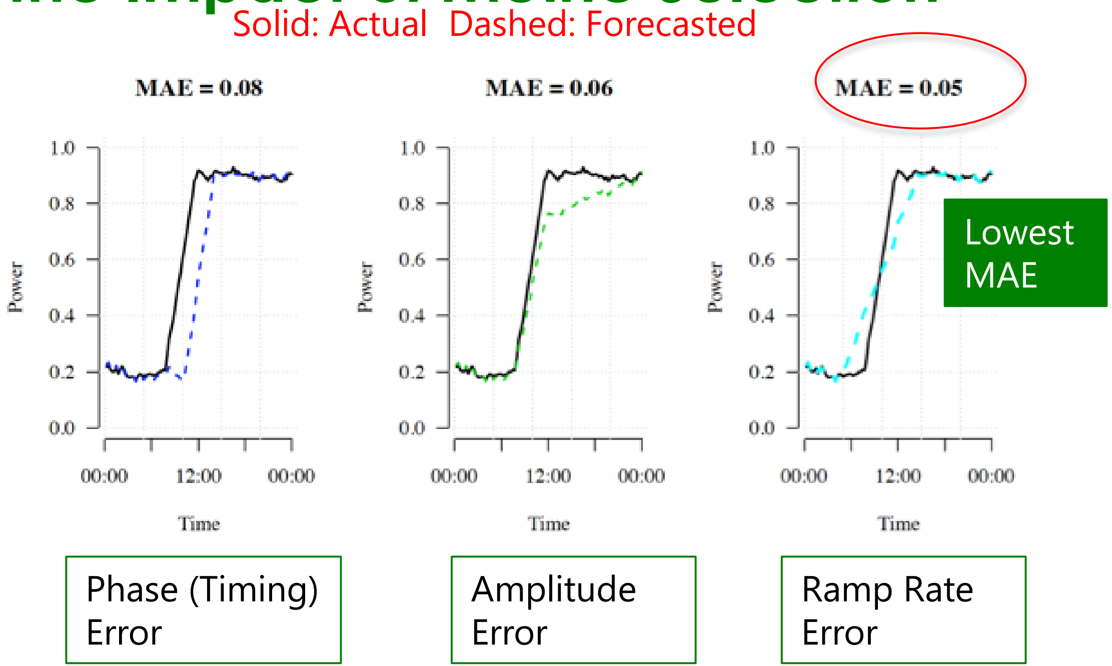


Relevance: degree of alignment between the evaluation metrics used for an evaluation and the true sensitivity of a user's application(s) to forecast error

- **Ideal Approach**: formulate a cost function that transforms forecast error to the application-related consequences of those errors (often very difficult)
- **Practical Alternative**: use a matrix of performance metrics that measure a range of forecast performance attributes
- **When using more than one relevant metric:**
    - Remember: ONE forecast can NOT be optimal for more than one metric;
    - Use separate forecast optimized for each metric if that attribute of performance is critical
- **When employing multiple ("N") forecast solutions:** choose the set that provides the best composite performance NOT the "N" best performing solutions

Forecast Performance Perception and Optimization: Example of the Impact of Metric Selection

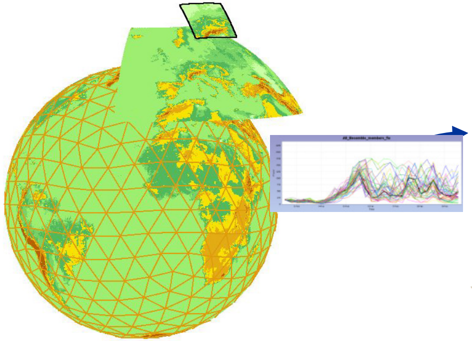
- **Ramp forecast example**
- **Typical case: user is interested in forecasting occurrence and attributes of ramp events for operational decision-making**
- **User evaluates forecast with a widely-used global metric such as MAE**
- **Provider optimizes to the user's selected metric**



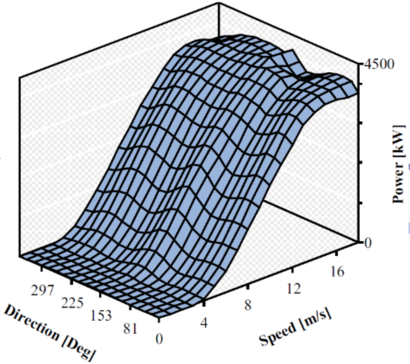
Verifying a ramp forecast with MAE/RMSE brings the forecast service provider into a dilemma: Tuning of forecast can (1) create good MAE scores or (2) serve the customer's needs → NOT BOTH

Key Points of Part 3

- ***All performance evaluations of potential or ongoing forecast solutions have a degree of uncertainty***
- *The uncertainty is associated with three attributes of the performance evaluation process evaluation process: (1) representativeness, (2) significance and (3) relevance*
- *A carefully designed and implemented evaluation process that considers the key issues in each of these three attributes can minimize the uncertainty and yield the most meaningful evaluation results*
- ***A disregard of these issues is likely to lead to uncertainty and/or decisions based on unrepresentative information***



Numerical Weather Prediction



Prediction model

End user

WP3:

- Decision support
- Scenarios
- Best Practice in Use
- Communication

Image sources: DWD, WAsP, Joensen/Nielsen/Madsen EWEC'97, Red Electrica de España.

WP3 Advanced Usage

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Use of Forecast Uncertainties in the Power Sector: State-of-the–Art of Business Practices

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***Abstract*—The work we present is an investigation on the state-of-the-art use of forecast uncertainties in the business practices of actors in the power systems sector that is part of the "IEA Wind Task 36: Wind Power Forecasting". The purpose of this task is to get an overview of the current use and application of probabilistic forecasts by actors in the power industry and investigate how they estimate and deal with uncertainties. The authors with expertise in probabilistic forecasting have been gathering information from the industry in order to identify the areas, where progress is needed and where it is difficult to achieve further progress. For this purpose, interview questions were compiled for different branches in the power industry and interviews carried out all around the world in the first six months of 2016. At this stage, we present and discuss results from this first round of interviews and draw preliminary conclusions outlining gaps in current forecasting methodologies and their use in the industry. At the end we provide some recommendations for next steps and further development with the objective to formulate guidelines for the use of uncertainty forecasts in the power market at a later stage.**

I. Introduction

The relevance of forecast uncertainties for wind power and other renewable energies grows as the penetration of these sources in the energy mix increases. Once a certain level of penetration is reached, ignoring the reliability of forecasts not only becomes expensive in terms of reserve roughly goes with wind speed to the power of three, and small errors and uncertainties are thus amplified and have an even higher impact compared to wind speed uncertainties. Weather development associated with fronts moving over large areas where wind is increasing rapidly over a short time are the most critical situations for a balance responsible party or a transmission system operator (TSO): it is under these circumstances that a deterministic forecast may be strongly incorrect and suppress steep ramping that can cause system security issues as well as large imbalances. Translated in the market, it means that there can be a sudden lack of power during a down-ramping event or too little flexible power that can be down-regulated fast and efficiently, which then results in curtailment. As long as the penetration level of wind is below 20% of generation, such uncertainty can usually be dealt with with a reasonable amount of reserves. As penetration increases, or in the case of island grids or badly interconnected grids, reserves and ancillary services grow above a desirable level.

In order to get an understanding of the current state of use of uncertainty forecasts and to find the gaps in the understanding of uncertainties and the associated forecasting tools and methods, we have been carrying out a study with a combination of questionnaires and interviews, which will

Use of probabilistic forecasting

Open Access journal paper

48 pages on the use of uncertainty forecasts in the power industry

Definition – Methods – Communication of Uncertainty – End User Cases – Pitfalls - Recommendations

Source: http://www.mdpi.com/1996-1073/10/9/1402/

energies

MDPI

Review

Towards Improved Understanding of the Applicability of Uncertainty Forecasts in the Electric Power Industry

Ricardo J. Bessa [1,*], Corinna Möhrlen [2], Vanessa Fundel [3], Malte Siefert [4], Jethro Browell [5], Sebastian Haglund El Gaidi [6], Bri-Mathias Hodge [7], Umit Cali [8] and George Kariniotakis [9]

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Academic Editor: David Wood
Received: 18 August 2017; Accepted: 8 September 2017; Published: 14 September 2017

Abstract: Around the world wind energy is starting to become a major energy provider in electricity markets, as well as participating in ancillary services markets to help maintain grid stability. The reliability of system operations and smooth integration of wind energy into electricity markets has been strongly supported by years of improvement in weather and wind power forecasting systems. Deterministic forecasts are still predominant in utility practice although truly optimal decisions and risk hedging are only possible with the adoption of uncertainty forecasts. One of the main barriers for the industrial adoption of uncertainty forecasts is the lack of understanding of its information content (e.g., its physical and statistical modeling) and standardization of uncertainty forecast products, which frequently leads to mistrust towards uncertainty forecasts and their applicability in practice. This paper aims at improving this understanding by establishing a common terminology and reviewing the methods to determine, estimate, and communicate the uncertainty in weather and wind power forecasts. This conceptual analysis of the state of the art highlights that: (i) end-users should start to look at the forecast's properties in order to map different uncertainty representations to specific wind energy-related user requirements; (ii) a multidisciplinary team is required to foster the integration of stochastic methods in the industry sector. A set of recommendations for standardization and improved training of operators are provided along with examples of best practices.

Broader paper on uncertainty forecasting

Prediction Models Designed to Prevent Significant Errors

By Jan Dobschinski, Ricardo Bessa, Pengwei Du, Kenneth Geisler, Sue Ellen Haupt, Matthias Lange, Corinna Möhrlen, Dora Nakafuji, and Miguel de la Torre Rodriguez


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Uncertainty Forecasting in a Nutshell

DOI: *10.1109/MPE.2017.2729100*

Digital Object Identifier 10.1109/MPE.2017.2729100
Date of publication: 18 October 2017

IT IS IN THE NATURE OF CHAOTIC ATMOspheric processes that weather forecasts will never be perfectly accurate. This natural fact poses challenges not only for private life, public safety, and traffic but also for electrical power systems with high shares of weather-dependent wind and solar power production.

To facilitate a secure and economic grid and market integration of renewable energy sources (RES), grid operators and electricity traders must know how much power RES within their systems will produce over the next hours and days. This is why RES forecast models have grown over the past decade to become indispensable tools for many stakeholders in the energy economy. Driven by increased grid stability requirements and market forces, forecast systems have become tailored to the end user's application and already perform reliably over long periods. Apart from a residually moderate forecast error, there are single extreme-error events that greatly affect grid operators.

Nevertheless, there are also forecast systems that provide additional information about the expected forecast uncertainty and estimations of both moderate and extreme errors in addition to the "best" single forecast. Such uncertainty forecasts warn the grid operator to prepare to take special actions to ensure grid stability.

The State of the Art in Forecast Generation

Today, some forecast systems have been developed specifically to predict the power production of single wind and solar units, differently sized portfolios, local transformer stations and subgrids, distribution and transmission grids, and entire countries. Nearly all forecast systems have one thing in common: they rely on numerical weather predictions (NWPs) to calculate the expected RES power production. The way to transform weather predictions into power forecasts depends crucially on the end user's application and the available plant configuration and measurement data. If historical measurements are available, forecast model developers often use statistical and machine-learning techniques to automatically find a relation between historical weather forecasts and simultaneously observed power measurements. If no historical measurement data are available, e.g., for new installations of RES units, the transformation of weather to power is often accomplished by physically based models that consider the unit's parameters to map the internal physical processes.

1540-7977/17©2017IEEE

november/december 2017

Minute-scale forecasting

Open Access review journal paper: 30 pages on minute-scale forecasting of wind power inclusive review on data assimilation techniques, probabilistic methods.

Use of minute-scale forecasting: (1) wind turbine and wind farm control, (2) power grid balancing, (3) energy trading and ancillary services

Source:https://www.mdpi.com/1996-1073/12/4/712

Energies 2019, 12, 712; doi:10.3390/en12040712
www.mdpi.com/journal/energies

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Article

Minute-Scale Forecasting of Wind Power—Results from the Collaborative Workshop of IEA Wind Task 32 and 36

Ines Würth [1,*], Laura Valldecabres [2], Elliot Simon [3], Corinna Möhrlen [4], Bahri Uzunoğlu [5,6], Ciaran Gilbert [7], Gregor Giebel [3], David Schlipf [8] and Anton Kaifel [9]

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check for updates

Abstract: The demand for minute-scale forecasts of wind power is continuously increasing with the growing penetration of renewable energy into the power grid, as grid operators need to ensure grid stability in the presence of variable power generation. For this reason, IEA Wind Tasks 32 and 36 together organized a workshop on "Very Short-Term Forecasting of Wind Power" in 2018 to discuss different approaches for the implementation of minute-scale forecasts into the power industry. IEA Wind is an international platform for the research community and industry. Task 32 tries to identify and mitigate barriers to the use of lidars in wind energy applications, while IEA Wind Task 36 focuses on improving the value of wind energy forecasts to the wind energy industry. The workshop identified three applications that need minute-scale forecasts: (1) wind turbine and wind farm control, (2) power grid balancing, (3) energy trading and ancillary services. The forecasting horizons for these applications range from around 1 s for turbine control to 60 min for energy market and grid control applications. The methods that can be applied to generate minute-scale forecasts rely on upstream data from remote sensing devices such as scanning lidars or radars, or are based on point measurements from met masts, turbines or profiling remote sensing devices. Upstream data needs to be propagated with advection models and point measurements can either be used in statistical time series models or assimilated into physical models. All methods have advantages but also shortcomings. The workshop's main conclusions were that there is a need for further investigations into the minute-scale forecasting methods for different use cases, and a cross-disciplinary exchange of different method experts should be established. Additionally, more efforts should be directed towards enhancing quality and reliability of the input measurement data.

Keywords: wind energy; minute-scale forecasting; forecasting horizon; Doppler lidar; Doppler radar; numerical weather prediction models

WP3 End use Workshop Glasgow

"Maximising Value from State-of-the-art Wind Power Forecasting Solutions"
Strathclyde University, Glasgow, 21 Jan 2020

- Talks by academia and industry (e.g. UK National Grid)
- Open Space discussion on RP, data and forecast value
- Game on value of probabilistic forecasts *(feel free to play it yourself!)*: https://mpib.eu.qualtrics.com/jfe/form/SV_d5aAY95q2mGI8El
- Streamed on YouTube: https://www.youtube.com/watch?v=1NOIr7jIuXI

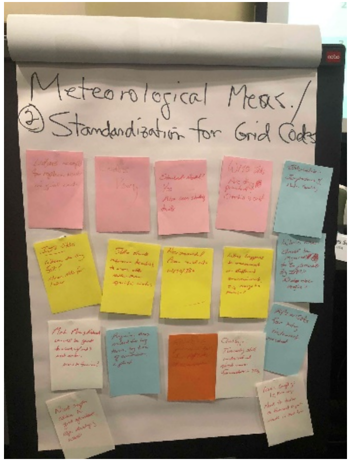
Topic: Meteorological Measurements and Instrumentation Standardization for Integration into Grid Codes

Results from 2 Workshops: ICEM 2019 & WIW 2019

Need for Industry Standard ?

→Need for best practices: BUT too strict standards are worse than non
→ No standards leads to chaotic data management
→ Instrumentation without maintenance: data looses value
→ Maintenance schedules: once, twice per year ?
→ Met instrumentation should be part of the turbine delivery/installation

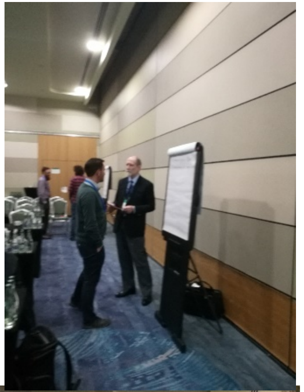
- **Dissemination**
    - No consensus on how to accomplish
    - ENSO-E is a potential body for dissemination
    - Forecasting still undervalued. Need more forecasters in TSOs.
    - Need simple advice to give operators, especially in the developing world



Topic: Meteorological Measurements and Instrumentation Standardization for Integration into Grid Codes

Results from 2 Workshops: ICEM 2019 & WIW 2019

- **General Agreement that Standards/RPs are Needed**
    - Grid codes vary from region to region
    - Concern about adopting WMO or similar standards, which may be expensive overkill for grid code purposes
    - Should reference traceability to standards but be instrument agnostic
    - Could suggest required measurements by IPPs at time of commissioning
    - Need education on importance of data quality
    - Need to address site selection for instrumentation
    - Need to tailor reporting interval to forecast model input needs



Data Science for Environmental Modelling and Renewables

- A Massive Open Online Course -

PRESENTATION SLIDES
ESIG Forecasting Workshop

Session 8

Jethro Browell
(presented by Corinna Möhrlen)

June 2018

St. Paul, MN, USA

supported by

Data Science for Environmental Modelling and Renewables

A Massive Open Online Course

6 Weeks, Equivalent to 5 ECTS Credits

Funded by: THE DATA LAB value from data

Hosted on: Future Learn

Course Outline

Week 1: Introduction

Week 2: R Bootcamp

Week 3: Patterns in temporal data

Week 4: Patterns in spatial, spatio-temporal and network data

Week 5: Open data, Citizen Science and Twitter

Week 6: Wind and Solar Power Forecasting

Go-Live in September 2018

supported by

Go-Live in September 2018

Week 6: Wind and Solar Power Forecasting

By the end of the week participants will be able to:

- Explain the principles of numerical weather prediction and make informed use of such data
- Produce basic deterministic and probabilistic wind and solar power forecasts
- Explain and apply the principles of forecast evaluation

Video Content

30-60 Minutes of video comprising a short lecture and interviews with forecast users.

Content Pages

1. Overview of the model chain: NWP → Physical/Statistical Model → Use and Evaluation
2. Numerical Weather Prediction: Basic Principles
3. Tools and methods in R
4. Deterministic Wind Power Forecasting
5. ***Principles of Deterministic Forecast Evaluation***
6. Deterministic Solar Power Forecasting
7. Introduction to Probabilistic Forecasting
8. Producing Probabilistic Forecasts
9. Principles of Probabilistic Forecast Evaluation
10. ***Best Practice for Users of Commercial Forecasts***

supported by

Statement for Discussion

Teaching should include standards or guidelines and provide a deeper understanding of the underlying fundamentals

Not having standards leaves teaching at

- fundamental principles
- missing knowledge on state of the art developments

Not having standards educates young professionals with

- very different skills
- no reference to relate new projects to

Wind power forecasting: IEA Wind Task 36 & future research issues

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Abstract. This paper presents the new International Energy Agency Wind Task 36 on Forecasting, and invites to collaborate within the group. Wind power forecasts have been used operatively for over 20 years. Despite this fact, there are still several possibilities to improve the forecasts, both from the weather prediction side and from the usage of the forecasts. The new International Energy Agency (IEA) Task on Forecasting for Wind Energy tries to organise international collaboration, among national meteorological centres with an interest and/or large projects on wind forecast improvements (NOAA, DWD, MetOffice, met.no, DMI, …), operational forecaster and forecast users.

Collected Issues

Nowcast (especially for difficult situations, thunderstorms, small lows, …)

Sub 1 hour temporal resolution

Meteorology below 1km spatial resolution

Stability issues, especially with daily pattern / (Nightly) Low level jets

Icing

Farm-Farm interaction / quality of direction forecast

Short-term ensembles

Ramps and other extremes

Spatio-temporal forecasting

Rapid Update Models (hourly, with hourly data assimilation)

Use of probabilistic forecasts and quality of the extreme quantiles

Do DSOs need different forecasts than TSOs?

Penalties for bad performance? Incentives for improved perf.?

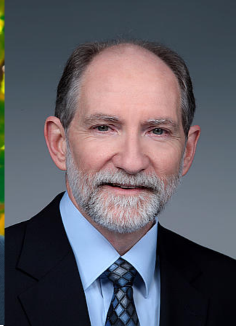
Seasonal forecasting? What's the business case?

Data assimilation (with non-linear Kalman filters, 4D Var, …)

Red: Important research, but (to be) done elsewhere

Green: We work on at least some aspects

www.IEAWindForecasting.dk



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