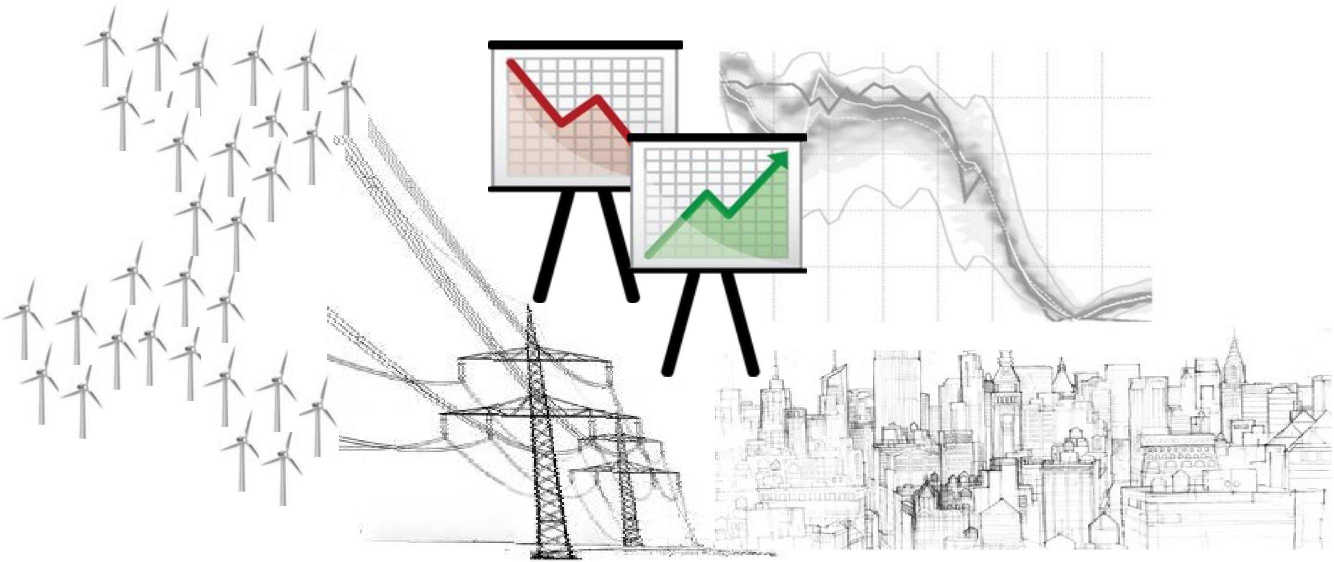
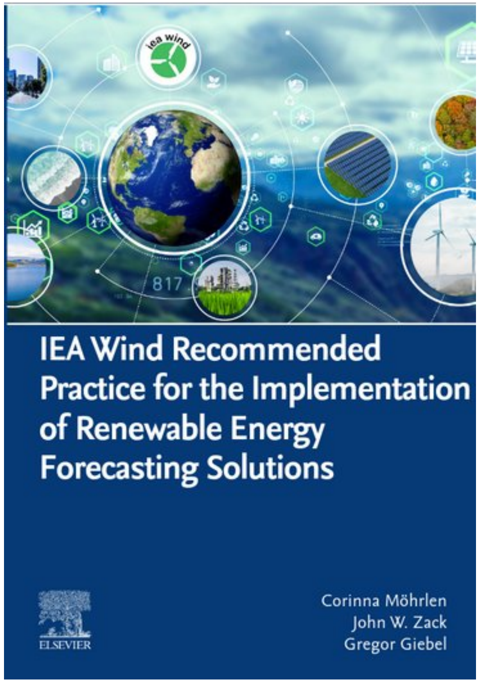
IEA Wind Task 51

IEA Wind Recommended Practice for the Implementation of Renewable energy Forecasting Solutions





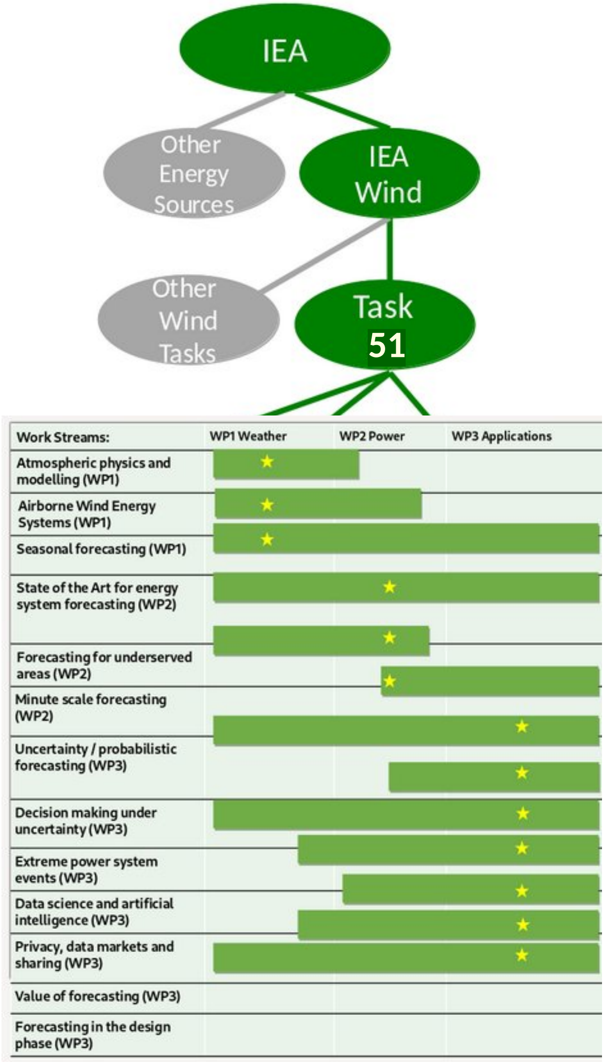
Introduction and Example Performance

Evaluation for met data at Fino & Alpha Ventus

RAVE Workshop Hamburg

11. May 2023

IEA Task 51 - Forecasting for the weather driven Energy System



What is the IEA (International Energy Agency)? (www.iea.org)

- International organization within OECD with 30 members countries and 8 associates
- Promotes global dialogue on energy, providing authoritative analysis through a wide range of publications
- **One activity: convenes panels of experts to address specific topics/issues**

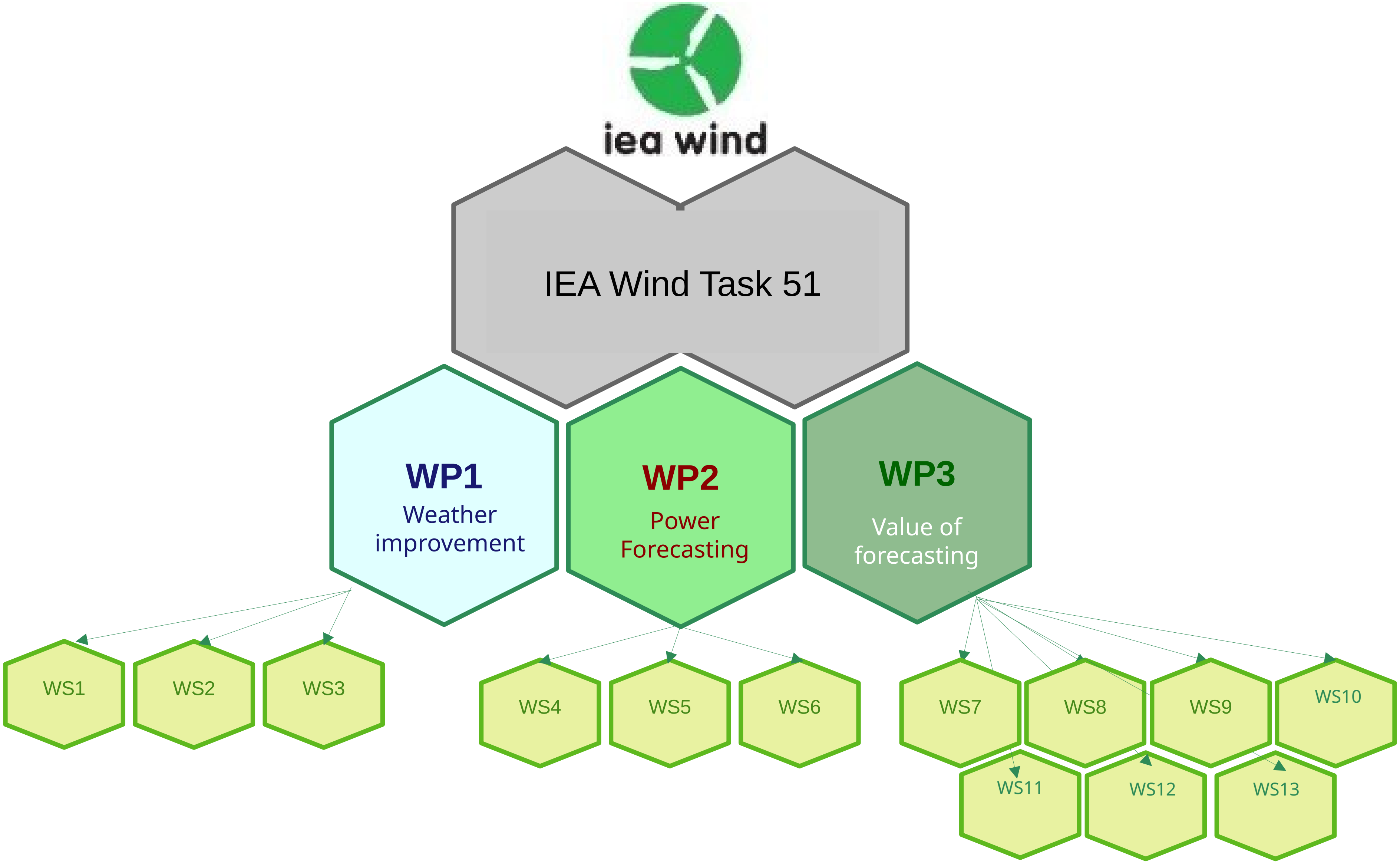
Task 51: Forecasting for the weather driven Energy System:

- One of 17 Tasks of IEA Wind: https://iea-wind.org/
- Task 36: Phase 1: 2016-2018; Phase 2: 2019-2021 **Task 51: Phase 3: 2022-2025**
- Operating Agent: Gregor Giebel of DTU Wind Energy
- Objective: facilitate international collaboration to **improve wind energy forecasts**
- Participants: (1) research organization and projects, (2) forecast providers, (3) policy-makers and (4) end-users & stakeholders

Task 51 Scope: 3 “Work Packages” / 13 “Workstreams”

- WP1: Global Coordination in Forecast Model Improvement
- WP2: Benchmarking, Predictability and Model Uncertainty
- WP3: Optimal Use of Forecasting Solutions

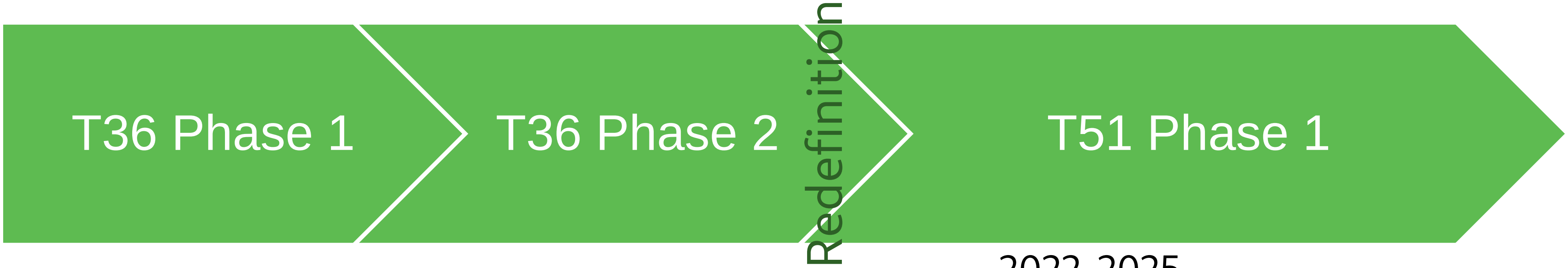
Task homepage: https://iea-wind.org/task51



iea wind
IEA Wind Task 51
WP1
Weather improvement
WP2
Power Forecasting
WP3
Value of forecasting
WS1
WS2
WS3
WS4
WS5
WS6
WS7
WS8
WS9
WS10
WS11
WS12
WS13

Forecasting for Wind Energy

2016-2018 2019-2021



2022-2025

Forecasting for the Weather Driven Energy System

Recommended Practice Book

Note

Elsevier Book

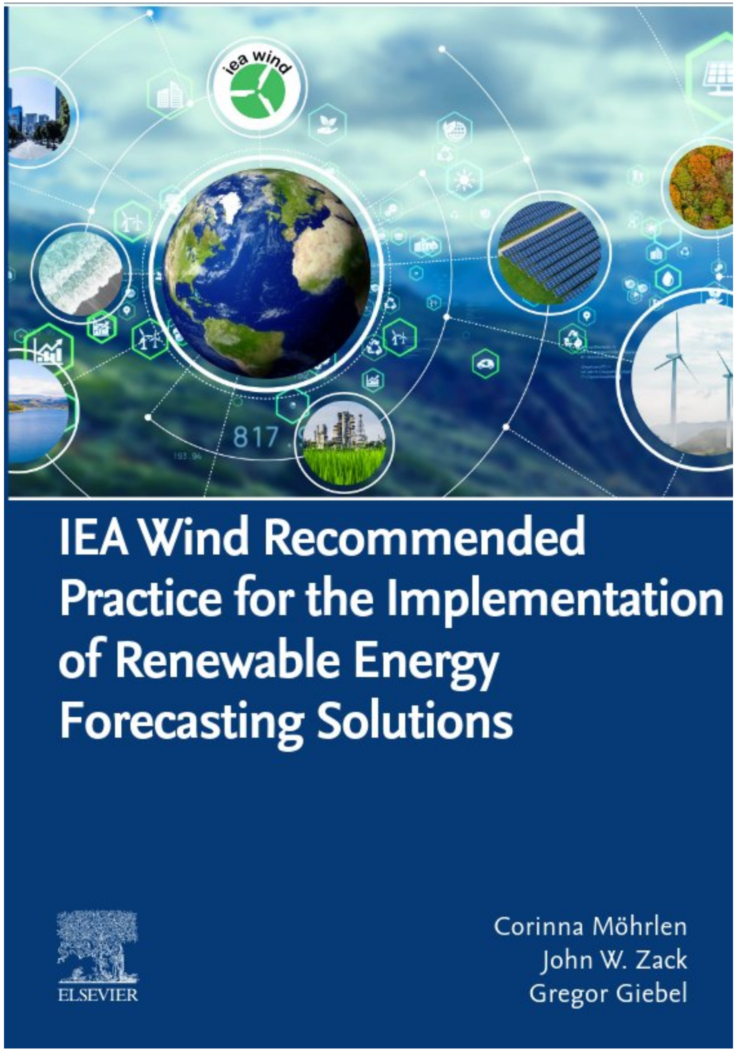
https://www.elsevier.com/books/iea-wind-recommended-practice-for-the-implementation-of-renewable-energy-forecasting-solutions/mohrlen/978-0-443-18681-3

Online OpenAccess:

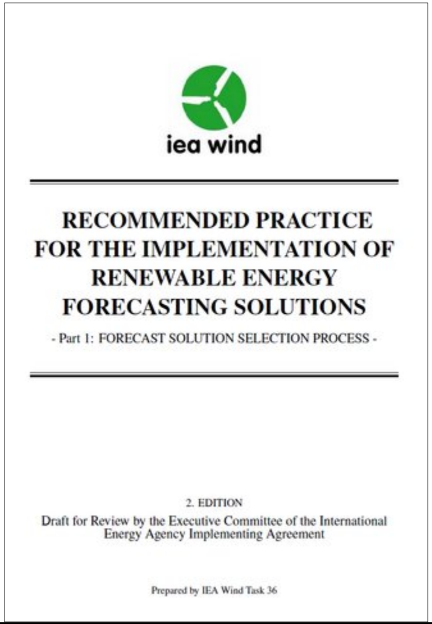
https://www.sciencedirect.com/book/9780443186813/iea-wind-recommended-practice-for-the-implementation-of-renewable-energy-forecasting-solutions

IEA Wind Task 51 Information

iea-wind.org → Task 51 → Publications → Recommended Practice



IEA Wind Recommended Practice for the Implementation of Renewable Energy Forecasting Solutions: Set of 4 Parts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RECOMMENDED PRACTICE FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

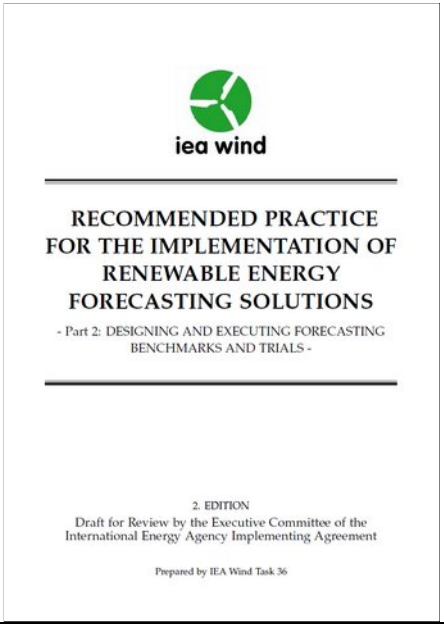
- Part 1: FORECAST SOLUTION SELECTION PROCESS -

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

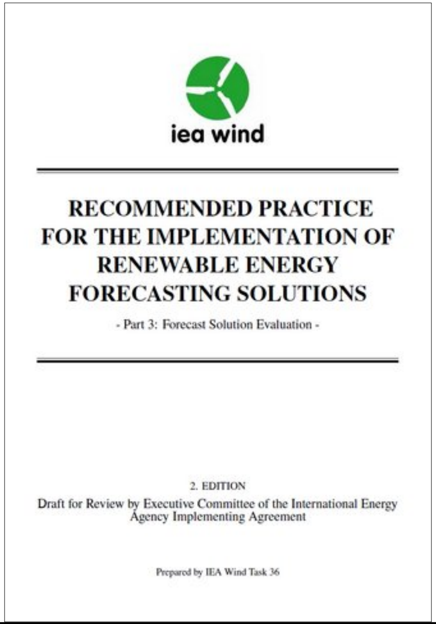
- Part 2: DESIGNING AND EXECUTING FORECASTING BENCHMARKS AND TRIALS -

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

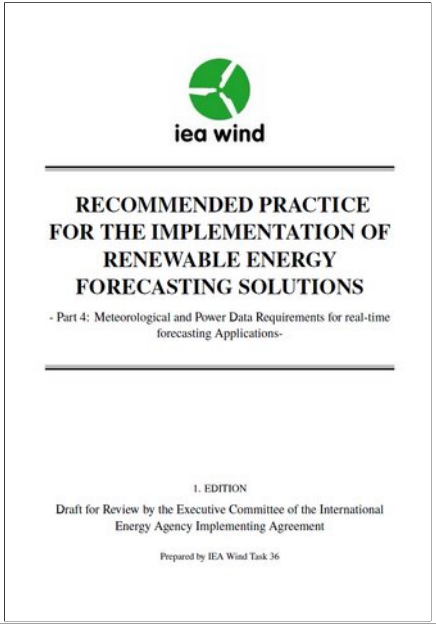
- Part 3: Forecast Solution Evaluation -

2. EDITION

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

Prepared by IEA Wind Task 36

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

Video Introduction

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

Summary & Introduction of the IEA Wind Recommended Practice for the Implementation of Renewable Energy Forecasting - Part 4:

Meteorological Data Requirements to be provided in the grid codes for real-time forecasting models

Data Requirements to be provided in the grid codes for real-time forecasting models

- BACKGROUND -

Combination of **actual wind measurements + trend from wind forecast** provide necessary input to a number of areas in grid operation: e.g.

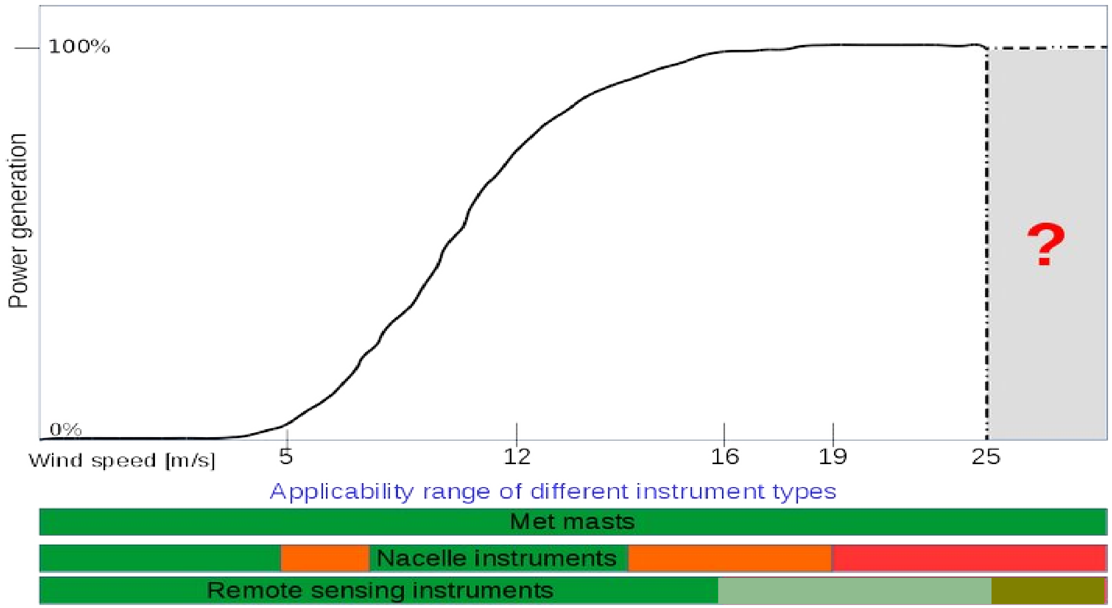
- forecast of high-speed shut-down events
- strong ramping events
- potential power computation
- compensation for curtailments
- etc.

Currently every ISO/TSO has to develop their own requirements for the grid code

→ a industry guideline would make this process much more efficient!

Data Requirements to be provided in the grid codes for real-time forecasting models

The most common instrumentation and their applicability

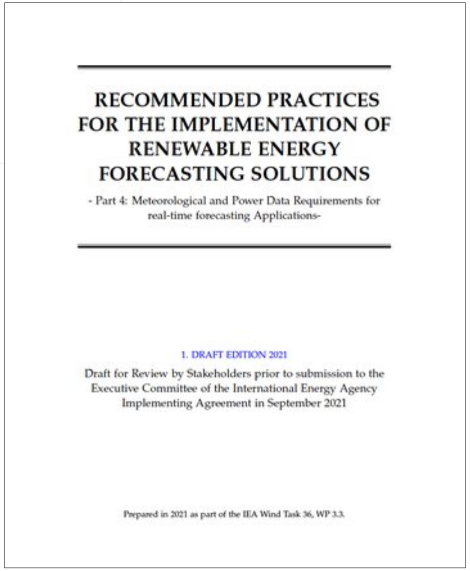


Met Masts
- cup/sonic anemometer

Nacelle instrumentation
- cup/sonic anemometer
- computation via pressure

Remote Sensing
- LiDAR
- SODAR
- RADAR

Part 4: Meteorological and Power Data Requirements For Real-time Forecasting Applications



RECOMMENDED PRACTICES FOR THE IMPLEMENTATION OF RENEWABLE ENERGY FORECASTING SOLUTIONS

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

1. DRAFT EDITION 2021

Draft for Review by Stakeholders prior to submission to the Executive Committee of the International Energy Agency Implementing Agreement in September 2021

Prepared in 2021 as part of the IEA Wind Task 36, WP 3.3.

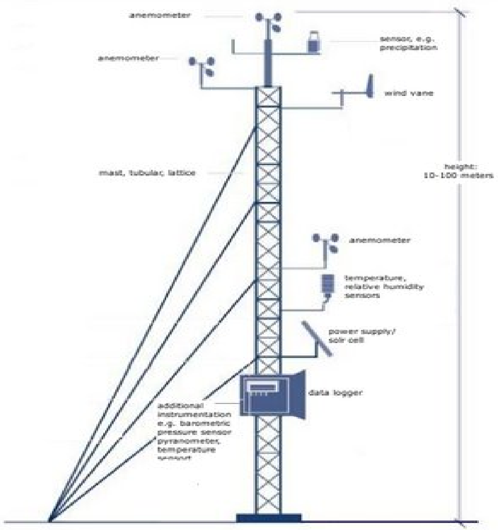
Target: Provide guidance for deploying and operating on-facility meteorological sensors to gather data for input into renewable power forecasts

Content:

1. Background and Objectives
2. Meteorological Instrumentation for Real-Time Operation
3. Power Measurements for Real-time Operation
4. Measurement Setup and Calibration
5. Assessment of Instrumentation Performance
6. Best Practice Recommendations
7. Examples of System Operator Measurement Requirements

Review of instrumentation and industry Best Practice

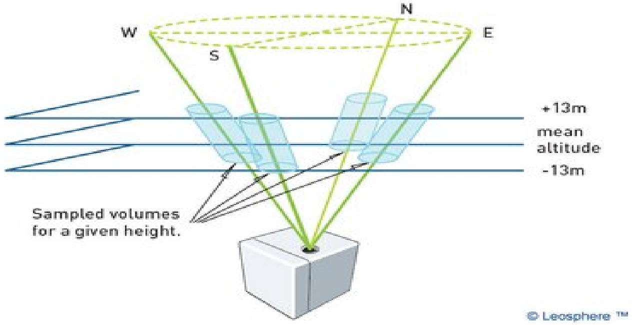
Meteorological Mast



Well known and tested

Standards for instruments

Remote Sensing Instruments

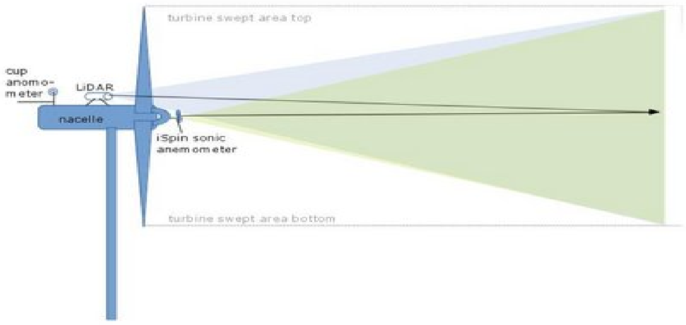


Less known in Wind Applications

Meteorologically interesting

Standards need to be adjusted for wind applications

Nacelle Instruments



Relative new application

“old” technology (cup anemometer) insufficient

advantages not tested for forecasting/grid security

Contents covered for application of Remote Sensing in the Recommended Practice Part 4 for real-time Applications

Remote Sensing Instrumentation for wind farms

- ground based lidars and sodars

Nacelle mounted instrumentation:

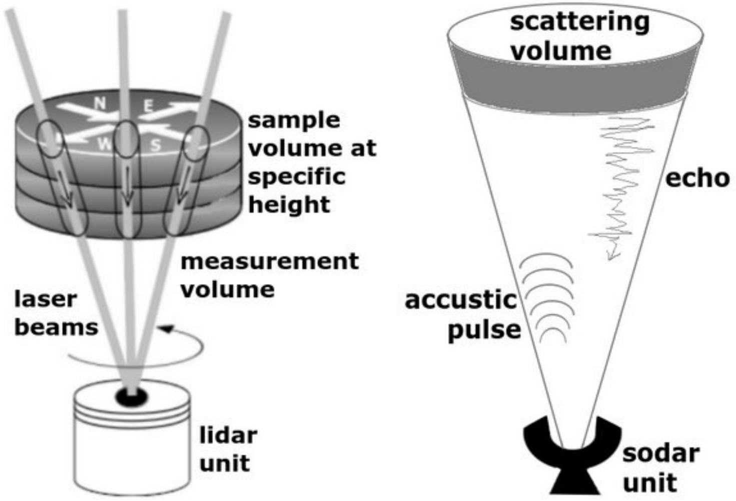
- Horizontally mounted lidars

Assessment of instrumentation performance

- yaw misalignment of wind turbine for scanning lidar

Quality control:

- specific quality control procedures for lidars



1st Real-world Application:

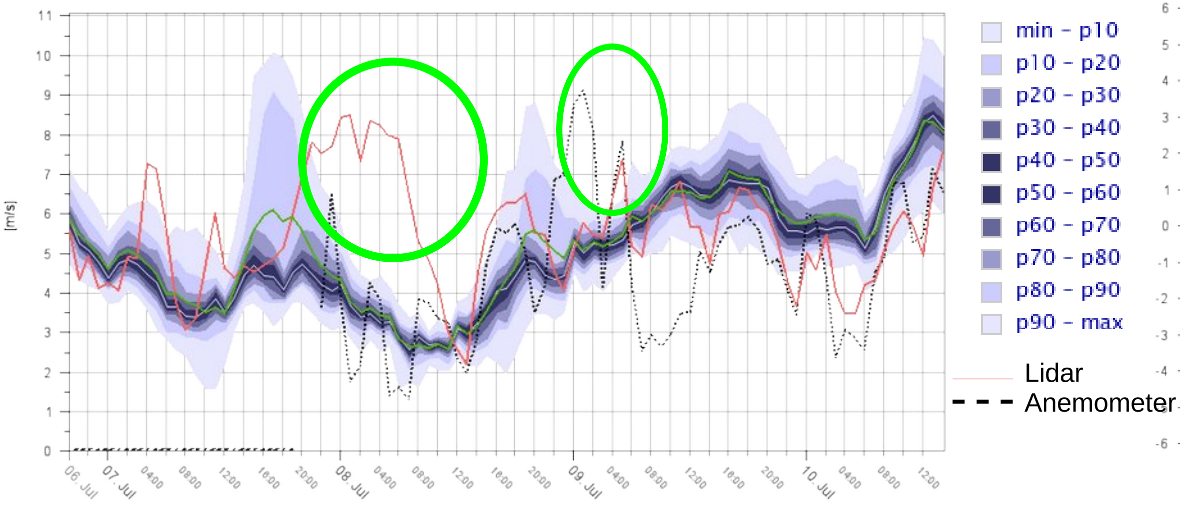
Recommendations are implemented by Irish TSOs, where **remote sensing <u>is allowed as alternative to met masts</u>**:

<u>Information</u>: "Eirgrid Met Mast and Alternatives Study" in 2019 (Online: Study and a journal article in coming soon in a Special Issue at the OpenAccess Journal IET Renewable Power Generation) and Irish GridCode for Meteorological Measurements (WFPS Meteorological Signals Guidelines)

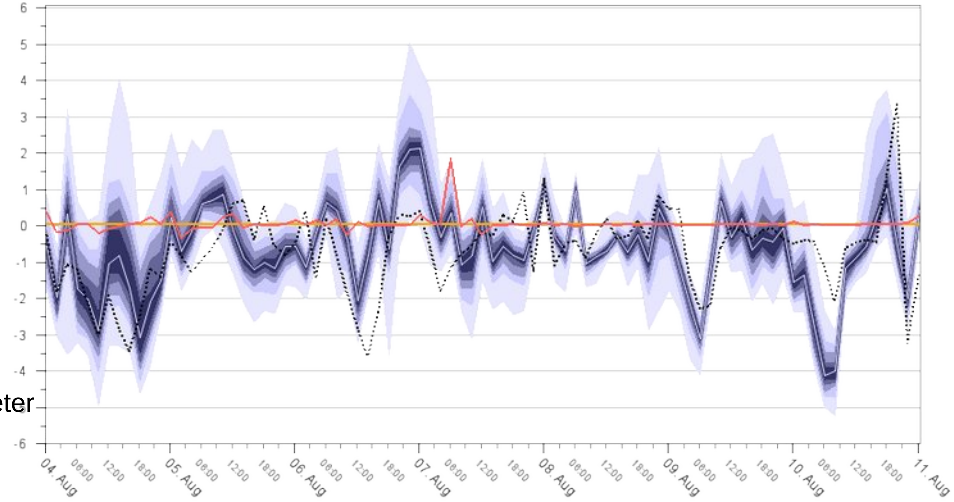
Findings from analysis of different measurement types in real-time environments

Remote sensing instruments are about to be mature
for real-time operation, but require more testing and pilots…

Just 2 typical challenging situations in a quality analysis…



Outliers on both Metmast & Lidar...



Difference between anemometer and
Lidar is == difference to forecast

Findings from analysis of measurement types

Remote sensing instruments are mature for
real-time operation, but require further development
for application in power grid operation:

- measurements must be raw or technical requirements must include
  delivery of maintenance and software updates
- lightning protection and recovery strategy after lightning
- measurements should be taken at several heights to take advantage of the instrument type
- instruments must be serviced and maintained by skilled staff
- version control must be maintained for signal processing
- wind characteristics data must be on wind turbine level
- LiDARs and SODARs in complex terrain require special consideration and testing

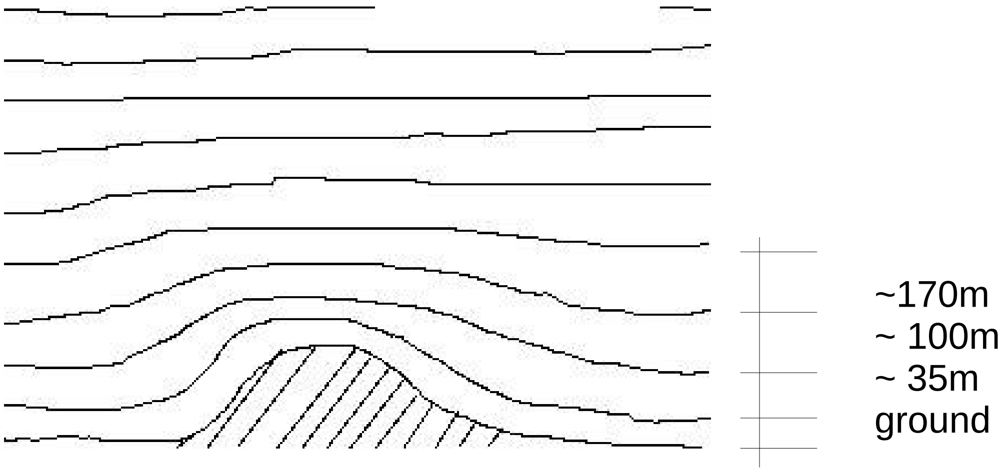
Recommendations for Met Data Requirements for real-time wind forecasting

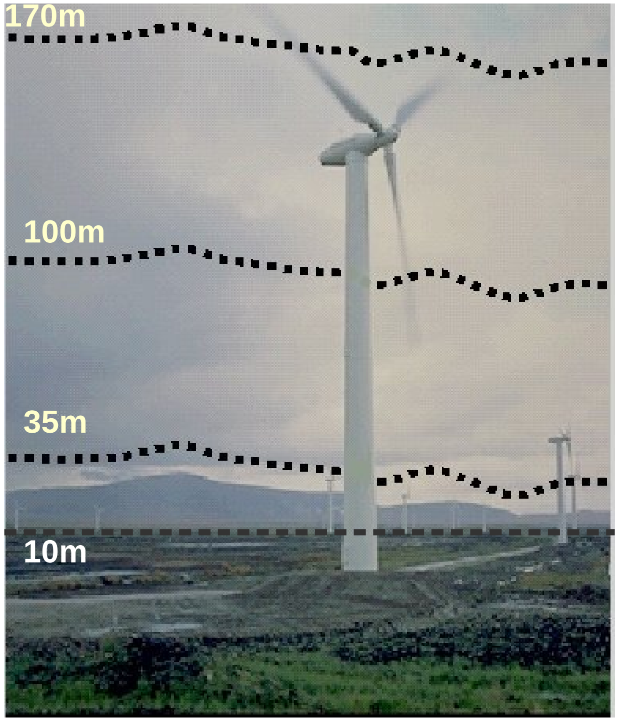
Requirement suggestions for wind farm accuracy of measurement instrumentation

Measurement	Units	Precision for Instantaneous Measurements (to the nearest...)	Range	Accuracy	Required /Optional
Wind Speed	Meters/Second (m/s)	0.1 m/s	0 to 50	±1m/s	R
Wind Direction	Degrees from True North	1 degree	0 to 360	±5°	R
Surface Pressure	HectoPascals (HPa)	1 hPa	800-1100	± 1.0 hPa at -20 ... 45 °C	R
Temperature	Degree Celsius	0.1° C	-50 to +50	±0.2 K in the range -27 ... +50°C	R
Dewpoint	Degrees Celsius (°C)	0.1° C	-50 to +50	±0.2 K in the range -27 ... +50°C	O
Relative Humidity	Percentage (%)	1.00%	0 to 100 %	±2% RH in the range 5- 95% RH at 10-40°C	O
Ice-up Parameter	Scale 0.0 to1.0	0.1	0 to 1	n/a	O/R
Precipitation	mm/min	0.1	0-11	2% until 25 mm/h 3% over 25 mm/h	O

Representativeness of measurements and fit to real-time NWP Forecasting

Background information about the relevance of measurement heights for the weather models





Lowest 3-4 model levels are always in the range
30-40|90-100|170-180m
→ common for all NWP models

Downscaling from model levels usually better than up-scaling from 10m wind!
→ 10m wind is a standardised, but calculation method for fixed heights

Quality control of meteorological measurements in the real-time environment

TSO/ISO	threshold [MW]	frequency [sec]	standing Data: geodata per wind farm	standing Data: geodata per turbine	Equipment*: met mast	Equipment*: nacelle	Equipment*: other	Met variables to be delivered: ws	wd	T2m	PS	DP	HUM	other	location agl
AESO	5	600	1	0	1	0	0	1	1	1	1	1	1	iceup	hub/2m
CAISO	1/5	4	1	1	1-2	1	0.5	1	1	1	1	0	0	0	hub(+10m)/2m
BPA	20	60	1	1	1	1	1	1	1	1	1	0	1	0	hub/2m
ERCOT	1	300	1	0	1	0	0	1	1	1	1	0	0	0	hub/2m
NYISO	1	30	1	0	1	0.5	0.5	1	1	1	1	1	1	0	hub/2m
PJM	10/100	10/2	1	0	1	0	0	1	1	1	1	0	0.5	0	hub/2m
HECO	all	900	1	0	1	0	1	1	1	1	1	0	0	0	hub+windNET
EIRGRID /SONI	10	5	1	0	0	0	1	1	1	1	1	0	0	0	hub(min35m)/2m
LITG	20	300	1	0	0	2	0	1	1	1	0	0	0	0	nacelle

equipment with a number < 1 means that it is allowed to use other equvivalent equipment to a met mast

Quality control of meteorological measurements in the real-time environment:

Assessment of instrumentation performance

- **Measurement data processing**

- **Uncertainty expression in measurements**
  → Known issues of uncertainty in specific instrumentation
  → Effects of uncertainty in nacelle wind speed measurements and mitigation methods
  → Application of nacelle wind speeds in real-time NWP data assimilation

- **General data quality control and quality assurance (QCQA)**
  → Historic quality control (QC)
  → Real-time quality control (QC)
  → Data screening in real-time wind and solar forecast applications
  → Data sampling thresholds in real-time wind and solar forecast applications

Quality control of meteorological measurements in the real-time environment:
Assessment of instrumentation performance

Application Areas for the Recommendations

1. System Operation, Balancing and Trading
- Situational awareness in critical weather events
- High-Speed Shutdown events
- Grid related down-regulation or curtailments
- Short-term forecasting with updates from measurements
  - Intra-day power plant balancing

2. Wind Turbine, Wind Farm and Solar Plant Operation and Monitoring
- Wind turbine and Power Plant Control
- Condition Monitoring

Quality control of meteorological measurements in the real-time environment:

Recommended Principles for the Selection of Instrumentation

The recommendations for the selection of instrumentation based on the following set of principles:

1. Accuracy requirements:

Accuracy requirements need to be defined for the application/project and aligned with the associated levels of effort necessary to operate and maintain the measurement system on under these constraints. An overall cost-performance determination should therefore always be carried out to adapt the budget to the accuracy requirements and vice versa.

2. Reliability requirements:

Reliability can be achieved with redundant instrumentation and/or high quality instrumentation. Redundancy enhances and ensures confidence in data quality. Selection of multiple instruments need to be aligned with the accuracy needs.

Quality control of meteorological measurements in the real-time environment:

Recommended Principles for Wind Power Performace Control

Performance control of wind farms and wind turbines is best conducted
in the following 3–4 steps:

a) Measuring basic meteorological parameters that can be used to compute power generation output

- wind speed and direction
- air temperature
- barometric pressure
- relative humidity

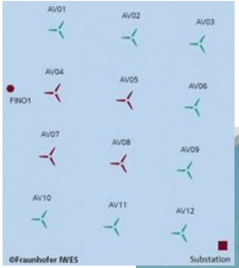
b) Conversion of the meteorological parameters into a power output

The best and recommended way is the IEC 61400-12-1 standard on power performance measurements, which is based on a physical formula (Equ. 2, chapter 8 [142])

c) Comparison of power output with measured and forecasted input variables

d) Visual Inspection with Ensemble generated Percentiles

Example Alpha Ventus +Fino1: Quality control of meteorological measurements in the real-time environment: Recommended test for data performance control



Pictures taken from RAVE Flyer, © by Fraunhofer IWES

	STATISTICS								
ID Period	PART 1 (ws,T2m,wdir,ps)	WindSPEED (bias, rmse,corr Realistic values)	Temperature (bias, rmse,corr Realistic values)	WindDIR (bias, rmse,corr Realistic values)	Pressure (bias, rmse,corr Realistic values)	Installed Capacity [MW]	Improve-ment >5%	Delivery Rate [%]	BIT MASK
Good DATA									
2021q3									
WAVUWT001	1111	1111	1111	1111	1111	60.0	2.19	99.8	15
capacity						60			
Bad DATA || MiSSING DATA + Delivery < 98.5%									
2021q2									
WAVM8T001	1001	1111	0001	0001	1111	5.0	6.57	10.6	9
WAVM7T001	1001	1111	0001	0001	1111	5.0	6.14	11.4	9
capacity						0			
Bad Data || Missing data + Requirement 2: Improvement < 5%									
2021q1									
WAVM7T001	0101	0111	1111	1001	1111	5.0	0	47.7	10
capacity						5.0			

Explanation of Available/missing Variables:

0 or -	bad/missing
1	windspeed (ws)
2	temperature (T)
3	ws+temperature
4	wind direction (wd)
6	wd + T
8	pressure (ps)
5	ws+ps
10	T+ps
11	ws+T+ps
12	wd+ps
13	ws+wd+ps
14	T+wd+ps
15	all variables delivered

1=ok, 0=bad, “-”=missing

Explanation of columns WS||WDIR||TEMP||PS	
1	BIAS
2	RMSE
3	CORR
4	data delivery of realistic values
1=ok, 0=bad, “-”=missing	

Quality control of meteorological measurements in the real-time environment

Analysis Period: June – Oct. 2021

→ Note: for a solid statement about an instrumentation, a period of minimum 1 year is ideal, not often not available

Observations:

- correlates well with model level 3
- the heights 90m and 100m show 18% missing data
- best data coverage is between 10m and 40m
- if signals stall, they stall over most levels, some with phase shifts of 2-3 time interval
- often missing data signals are associated with precipitation and/or high wind speeds

NOTE: These test are to **understand the pattern** in which instruments may have **difficulties to provide reliable data in real-time**, **NOT** to discourage use of instruments in general

consistent with literature

Measurement heights	% missing Data	MEAN [m/s]	BIAS [%inst. Cap]	MAE [%inst. Cap]	RMSE [%inst. Cap]	#height agl. [m]
Wind Speed (m/s) at 180m	13.4	8.6	0.01	1.42	1.86	179
Wind Speed (m/s) at 155m	13.3	8.4	-	-	-	
Wind Speed (m/s) at 127m	14.8	8.1	-	-	-	
Wind Speed (m/s) at 100m	18.4	7.6	0.41	1.35	1.74	98
Wind Speed (m/s) at 90m	18.3	7.4	-	-	-	
Wind Speed (m/s) at 79m	17.4	7.2	-	-	-	
Wind Speed (m/s) at 69m	15.8	7.0	-	-	-	
Wind Speed (m/s) at 49m	10.5	6.6	-	-	-	
Wind Speed (m/s) at 38m	6.0	6.4	0.44	1.22	1.55	38
Wind Speed (m/s) at 29m	4.0	6.2	-	-	-	
Wind Speed (m/s) at 10m	1.7	5.3	-0.63	1.11	1.44	10

model level 3 at ~170m

model level 2 at ~100m

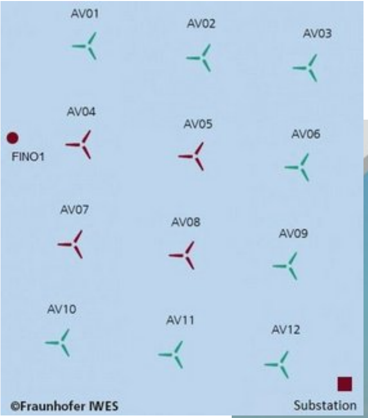
Table shows the mean of the measurements and the failure rate of the tested instrument.

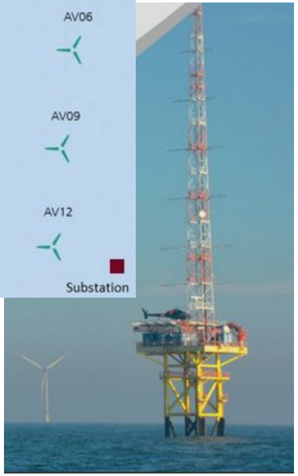
model level 1 at ~35m

10m wind

Example Alpha Ventus + Fino1: Quality control of meteorological measurements in the real-time environment

We reverse verification: measurement versus forecasts!





Pictures taken from RAVE Flyer, © by Fraunhofer IWES

Variable list and their threshold error limits

Var Number	Variable Name	Mininum Correlation	Maximum |Bias|	Maximum MAE
1	WindSpeed	0.65	3.0	3.0
2	AirTemp	0.75	2.0	2.5
3	WindDirection	0.55	13.0	20.0
4	AirPressure	0.9	50.0	85.0

Exemplary results from the Quality analysis of 6 Turbines & UW

Statis-tic rank	Windfarm ID	Test: ws|temp|wd|ps	wind speed WS	temp-erature T	wind direction WD	surface pressure PS	Description
1	AV07	1111	111	111	111	111	all tests ok
2	AV08	1111	111	111	111	111	all tests ok
3	UW	1110	111	111	111	000	PS fails all tests
4	AV09	1101	111	111	100	111	WD fails, except for WD(BIAS) OK
5	AV10	1101	111	111	101	111	WD fails, except for WD(MAE) OK
6	AV11	1010	111	000	111	110	T fails on all
7	AV12	1001	111	000	101	111	T fails and WD(MAE) fails

Criteria for "goodness" of data

Variable	unit	lower Limit	upper Limit
Wind speed (WS)	m/s	0	40
Wind direction (WD)	deg	0	360
Temperature (T)	°C	-40	40
Surface pressure (PS)	hPa	800	1100

Fino data: Wind, Temperature and Pressure
Turbines/UW: Wind & Power

Quality control of meteorological measurements in the real-time environment:

CONCLUSIONS & OUTLOOK

Application Areas for the Recommendations

1. System Operation, Balancing and Trading

- Situational awareness in critical weather events
- High-Speed Shutdown events
- Grid related down-regulation or curtailments
- Short-term forecasting with updates from measurements
    - Intra-day power plant balancing

2. Wind Turbine, Wind Farm and Solar Plant Operation and Monitoring

- Wind turbine and Power Plant Control
- Condition Monitoring

THANK YOU FOR YOUR ATTENTION

Follow us:

Project webpage: http://iea-wind.org/task51

Task-page: https://iea-wind.org/task51/task51-publications/task51-recommended-practices/

Publications: https://iea-wind.org/task51/task51-publications

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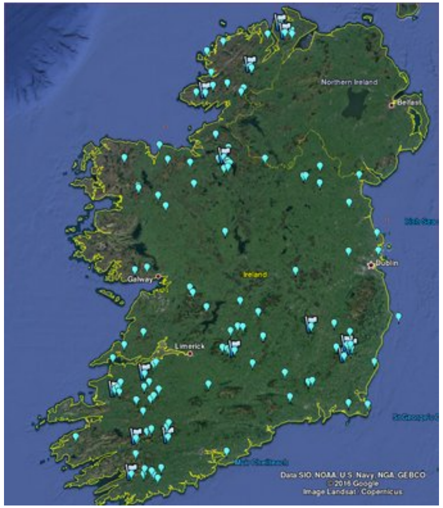
BACKUP SLIDES

Example Ireland: Quality control of meteorological measurements in the real-time environment



Variable list and their threshold error limits

Var Number	Variable Name	Mininum Correlation	Maximum |Bias|	Maximum MAE
1	WindSpeed	0.65	3	
2	AirTemp	0.75	2	2.5
3	WindDirection	0.55	13	20
4	AirPressure	0.9	50	85

Exemplary results from the Quality analysis of 15 selected sites

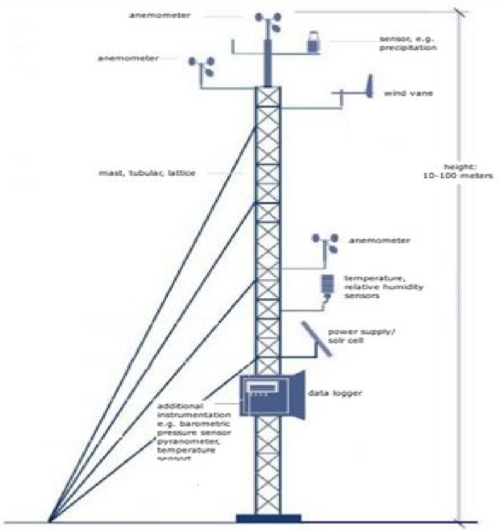
Stat-Istic rank	Windfarm ID	Test: ws|temp|wd|ps	wind speed WS	temp-erature T	wind direction WD	surface pressure PS	
1	IE001	1111	111	111	111	111	all tests ok
2	IE012	1111	111	111	111	111	all tests ok
3	IE002	1111	111	111	111	111	all tests ok
4	IE003	1111	111	111	111	111	all tests ok
5	IE009	1111	111	111	111	111	all tests ok
6	IE005	1110	111	111	111	000	PS fails all tests
7	IE007	1101	111	111	100	111	WD fails, except for WD(BIAS) OK
8	IE010	1101	111	111	101	111	WD fails, except for WD(MAE) OK
9	IE006	1101	111	111	101	111	WD fails, except for WD(MAE) OK
10	IE013	1101	111	111	101	111	WD fails, except for WD(MAE) OK
11	IE011	1101	111	111	000	111	WD fails
12	IE015	1101	111	111	001	111	WD fails, except for WD(CORR) OK
13	IE014	1011	111	000	111	111	T fails on all
14	IE008	1010	111	000	111	110	T fails on all
15	IE004	1001	111	000	101	111	T fails and WD(MAE) fails

Criteria for “goodness” of data

Variable	unit	lower Limit	upper Limit
Wind speed (WS)	m/s	0	40
Wind direction (WD)	deg	0	360
Temperature (T)	°C	-40	40
Surface pressure (PS)	hPa	800	1100

Review of instrumentation and industry Best Practice

Meteorological Mast



simple, realiable, less information

more information, but also more complex and more expensive….

Cup anemometers
well tested and standardised

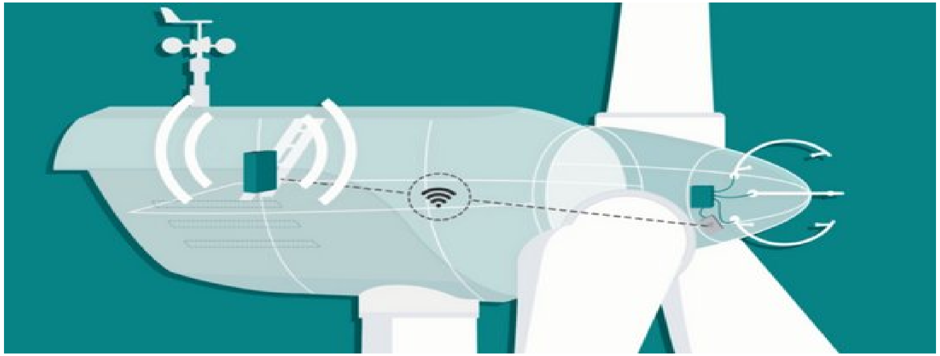
IEC 61400-12-1/2 and ISO/IEC 17025 standards describe how these instruments must be:

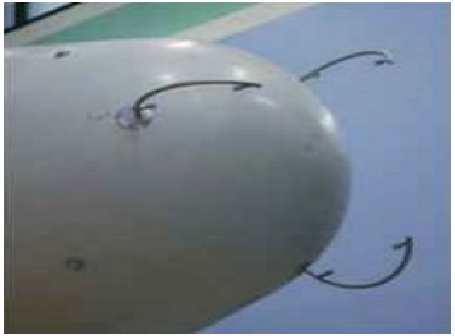
- calibrated
- mounted
- describe the process and the integrity of the measurement processes
- describe design of mast, instruments and measuring procedures.

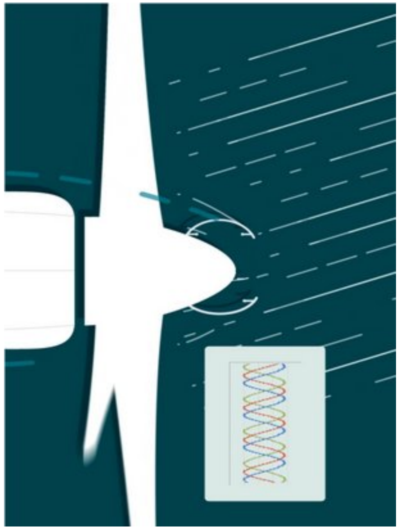
3D sonic anemometers have:
long tradition in atmospheric science and meteorology

- boundary layer studies of turbulence intensity
- phenomena like low level jets

Review of instrumentation and industry Best Practice







The iSpin technology claims to solve the following issues:

- monitor the air density corrected power curve
- monitor and correct yaw misalignments
- Observe turbulence intensity allowing you to make informed choices between power production and reduced turbine loads
- Monitor flow inclinations

Most critical for forecasting application:
- computation of flow
- not proven in real-time yet

Findings from analysis of measurement types

Identified issues with **nacelle mounted measurements**:

induction: nacelle measurement errors followed in large the angle of pitched blades (5% pitched blades equivalent 5% measurement error)

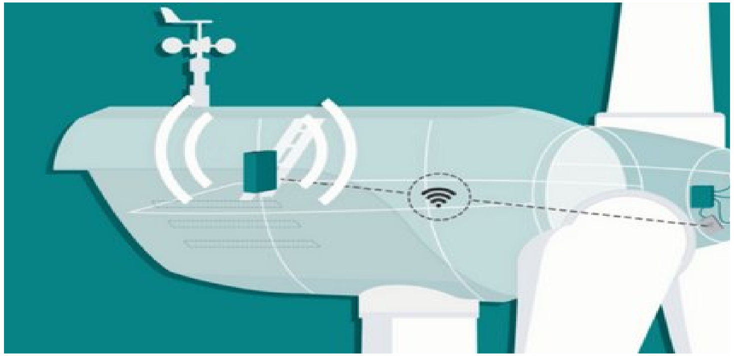
flow disturbances: changing direction gives changing inclination angles and wrong changes in wind speeds

wake effects from other turbines and of cup anemometers, where the turbine was subject to wake effects at certain directions

over-speeding of cup anemometer with errors > 10%

offsets in wind direction

snow and icing



Findings from analysis of remote sensing measurement types

Findings from analysis of **remote sensing instruments**:

ADVANTAGES
Availability of vertical wind profile information

Volume-averaged versus point measurement

No planning permission required

DISADVANTAGES
Variable data quality

Data outages correlated with specific weather types

Data frequency

The instruments are interesting, especially for situational awareness, but show highest reliability issues under specific weather situations
--→ NOTE: LIDARs and SODARs complement each other