Introduction to Danish wind power development and grid integration

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Introduction to Danish wind power development and grid integration

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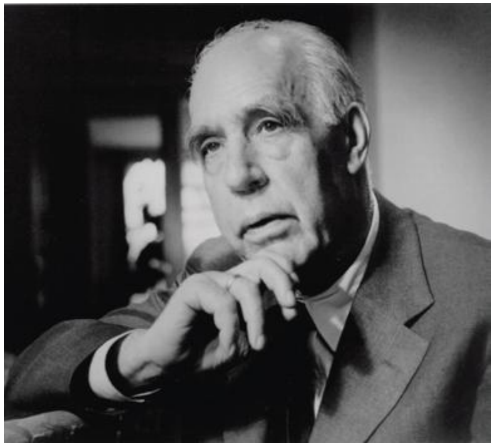
Technical University of Denmark

Outline

- Introduction
- Denmark – a demonstration country for wind energy
- R&D
- Grid integration challenges

Some Risø history in brief

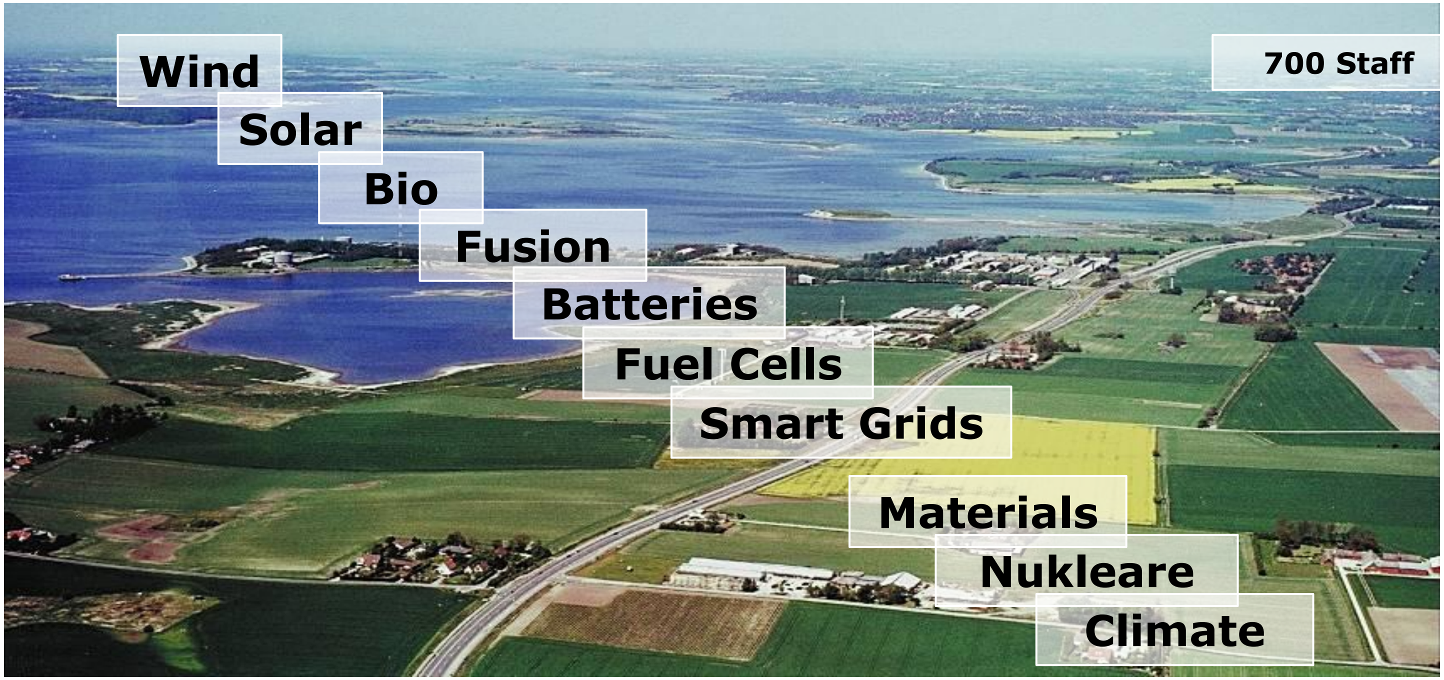


- **1954** Nuclear Energy Committee headed by Niels Bohr
- **1958** 3 nuclear reactors under construction
- **1976** Wind energy research starts
- **1985** No Nuclear Power in Denmark energy plans
- **2000** Decommissioning of the last nuclear reactor is
- **2005** Sustainable energy central in strategy
- **2007** Part of Technical University of Denmark (DTU)

Risø is part of the Technical University of Denmark (DTU)

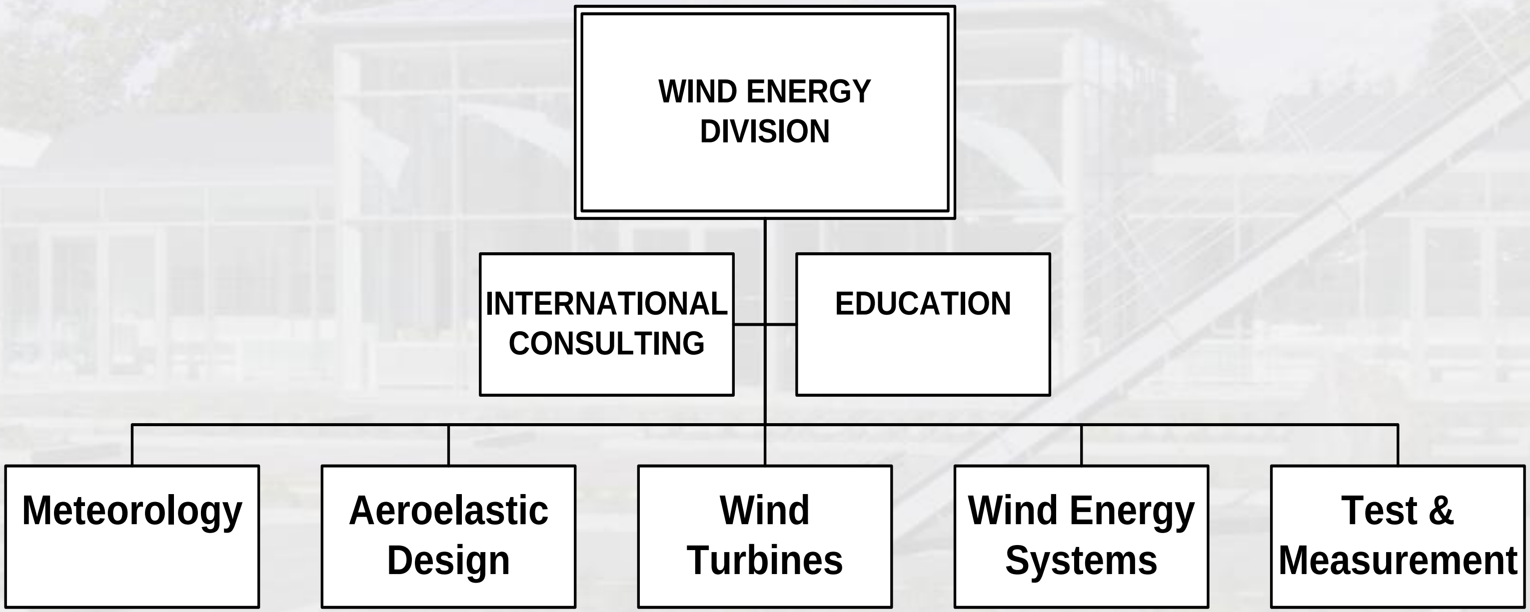
- January 2007, Risø National Laboratory merged with the Technical University of Denmark (DTU)
- Research, education, innovation and assistance of public authorities
- 7,000 students
- 4,200 employees, 2,000 of whom are scientists
- Annual revenue of DKK 3.2 billion

Risø DTU is the national laboratory for sustainable energy



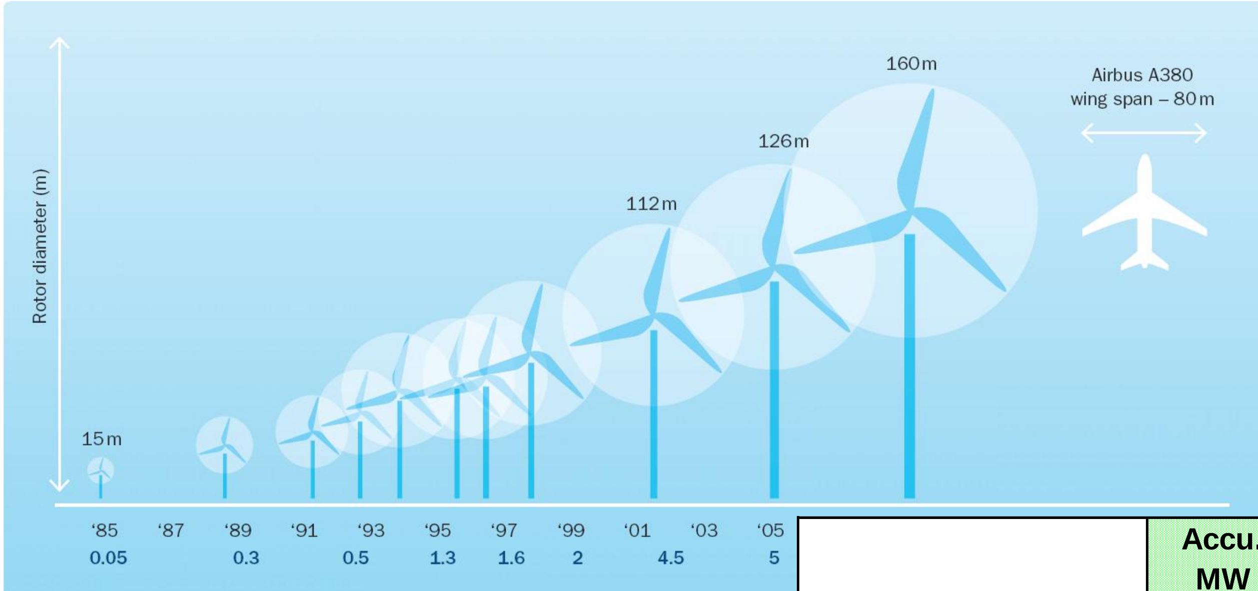
Wind Energy at DTU

Risø DTU - Wind Energy Division (150 staff)



Risø DTU - Systems Analyses Division
Risø DTU - Materials Research Division
DTU-Mechanical Engineering
DTU-Electrical Engineering
DTU-Informatics

Commercial wind turbines
size development - Top-10 list of suppliers 2010

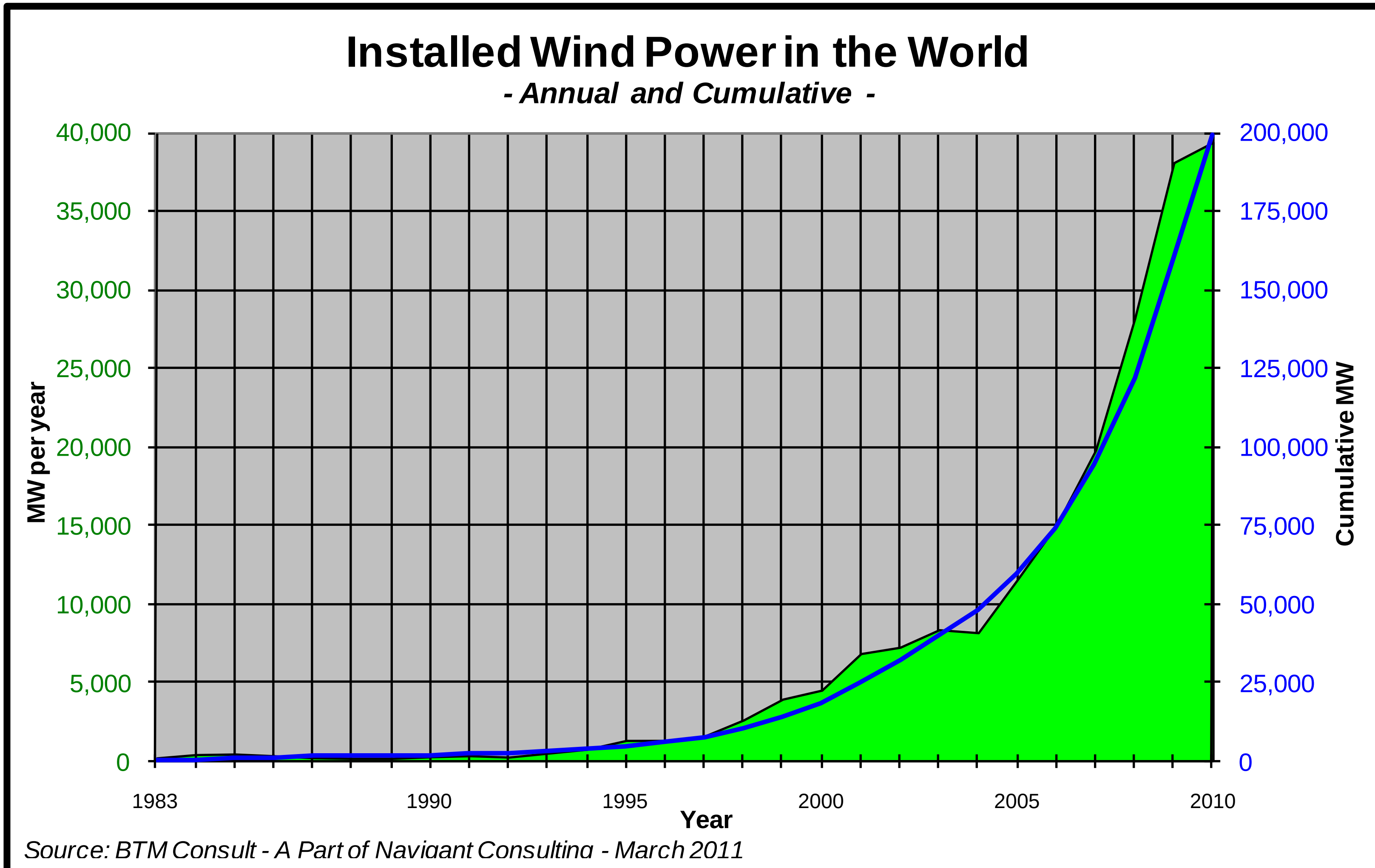


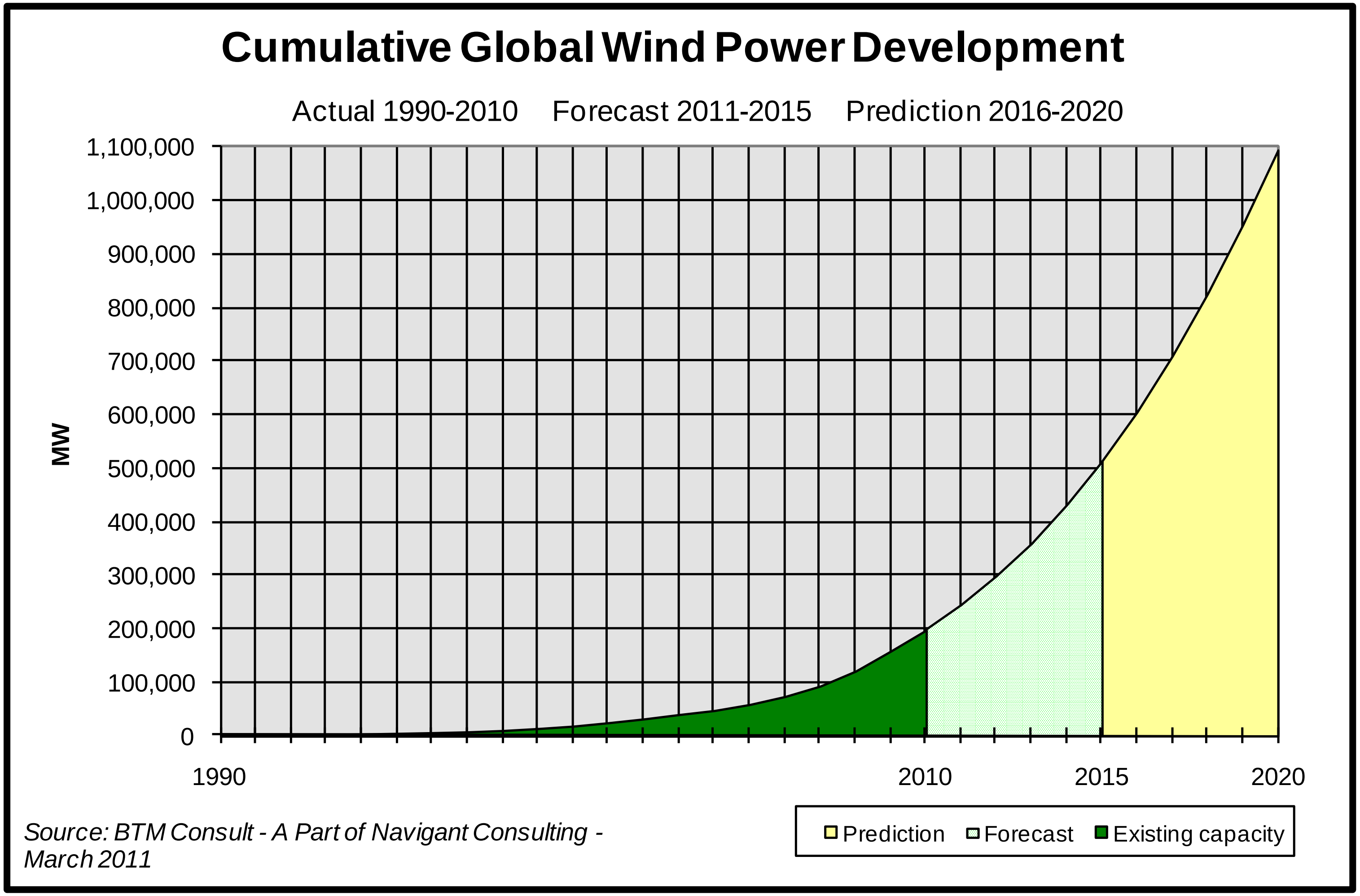
Source: TPWind

	Accu. MW 2009	Supplied MW 2010	Share 2010 %	Accu. MW 2010	Share accu. %
VESTAS (DK)	39,705	5,842	14.8%	45,547	22.8%
SINOVEL (PRC)	5,658	4,386	11.1%	10,044	5.0%
GE WIND (US)	23,075	3,796	9.6%	26,871	13.5%
GOLDWIND (PRC)	5,315	3,740	9.5%	9,055	4.5%
ENERCON (GE)	19,798	2,846	7.2%	22,644	11.3%
SUZLON GROUP (IND)	14,565	2,736	6.9%	17,301	8.7%
DONGFANG (PRC)	3,765	2,624	6.7%	6,389	3.2%
GAMESA (ES)	19,225	2,587	6.6%	21,812	10.9%
SIEMENS (DK)	11,213	2,325	5.9%	13,538	6.8%
UNITED POWER (PRC)	792	1,643	4.2%	2,435	1.2%
Others	22,045	8,247	20.9%	30,292	15.2%
Total	**165,156**	**40,771**	**103%**	**205,927**	**103%**

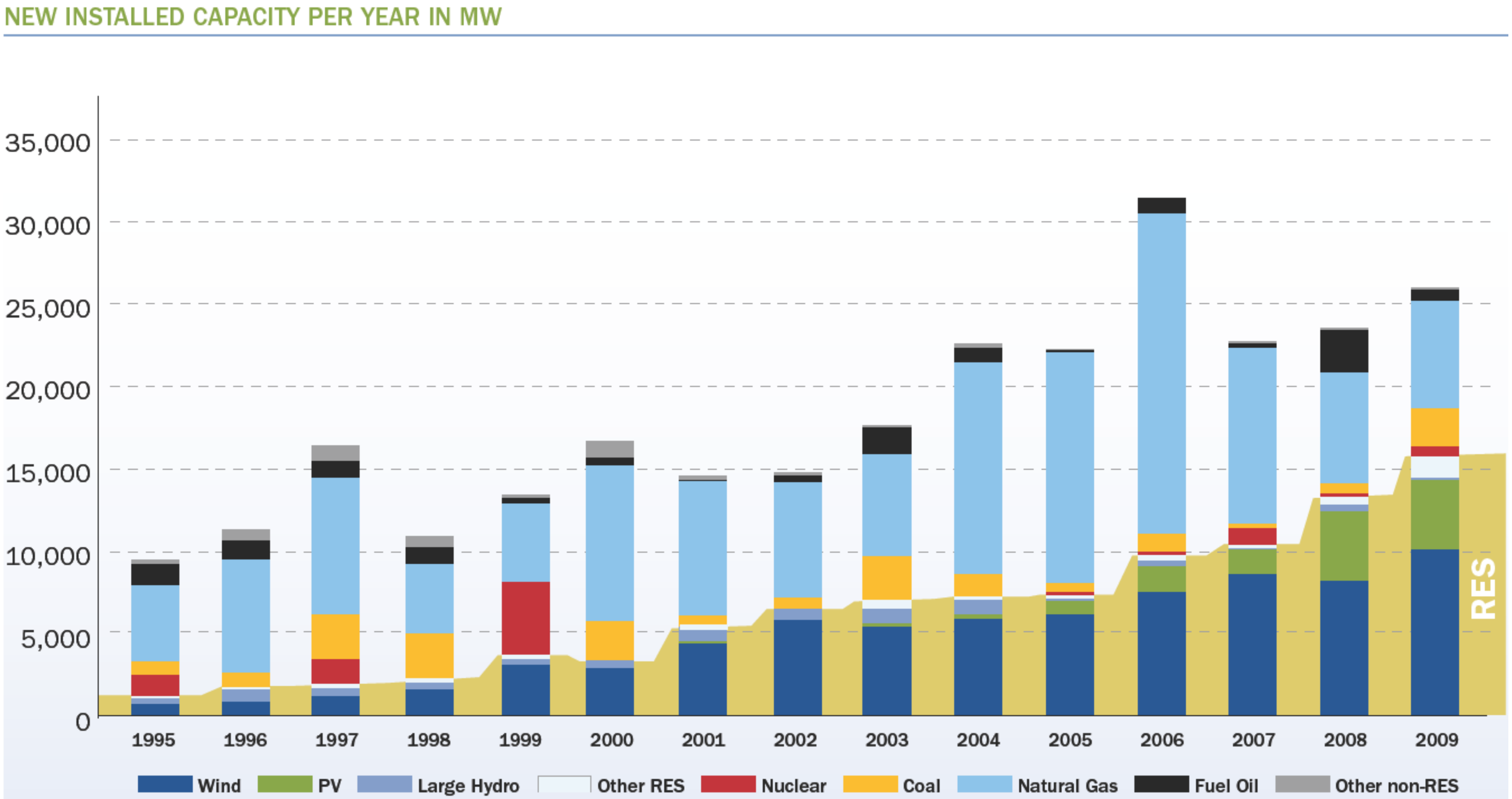
Source: BTM Consult - A Part of Navigant Consulting - March 2011

Wind energy development



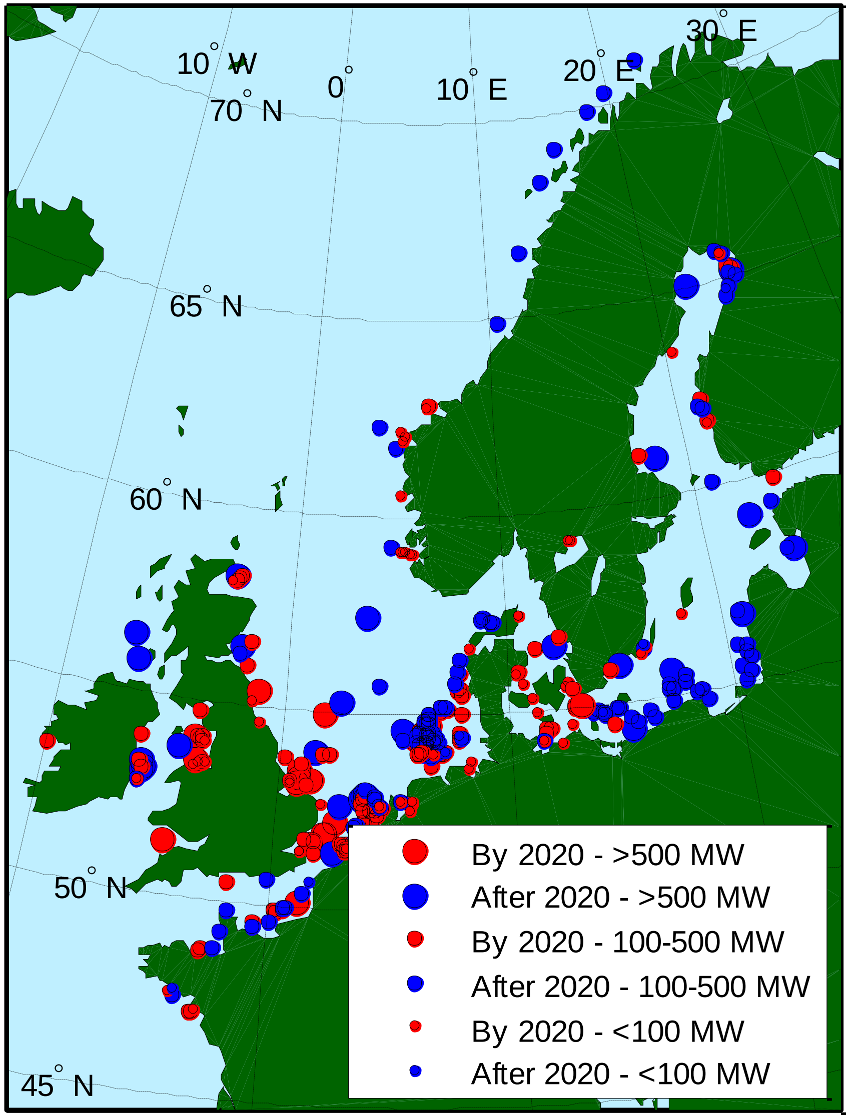

Cumulative Global Wind Power Development
Actual 1990-2010
Forecast 2011-2015
Prediction 2016-2020
MW
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1990
2010
2015
2020
Source: BTM Consult - A Part of Navigant Consulting - March 2011
Prediction
Forecast
Existing capacity

Wind power share of new installed capacity (source: EWEA)

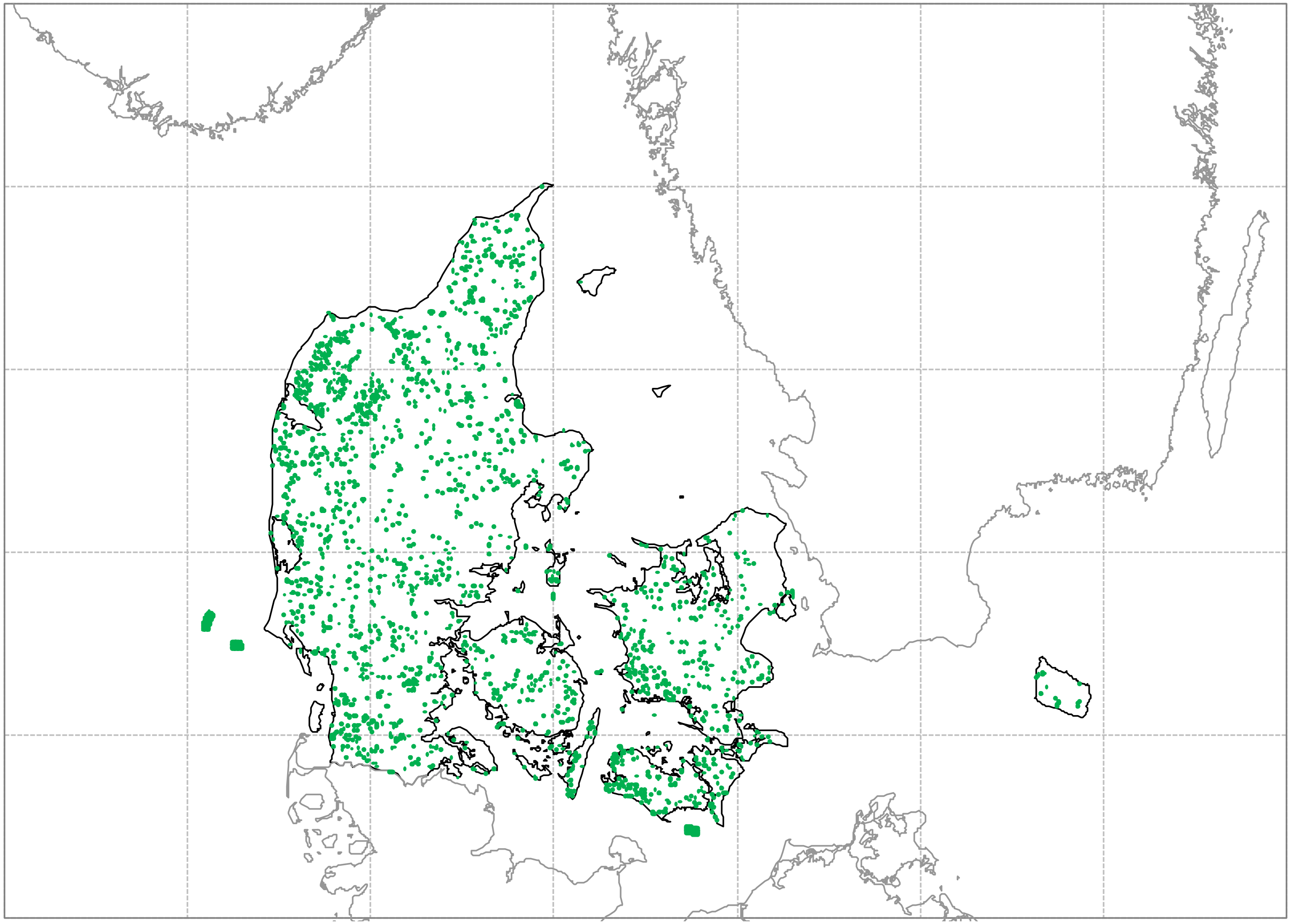


Offshore wind power development scenarios

A preliminary assessment by the EU-TWENTIES project of the geographical distribution of offshore wind farms in northern Europe by 2020 and 2030

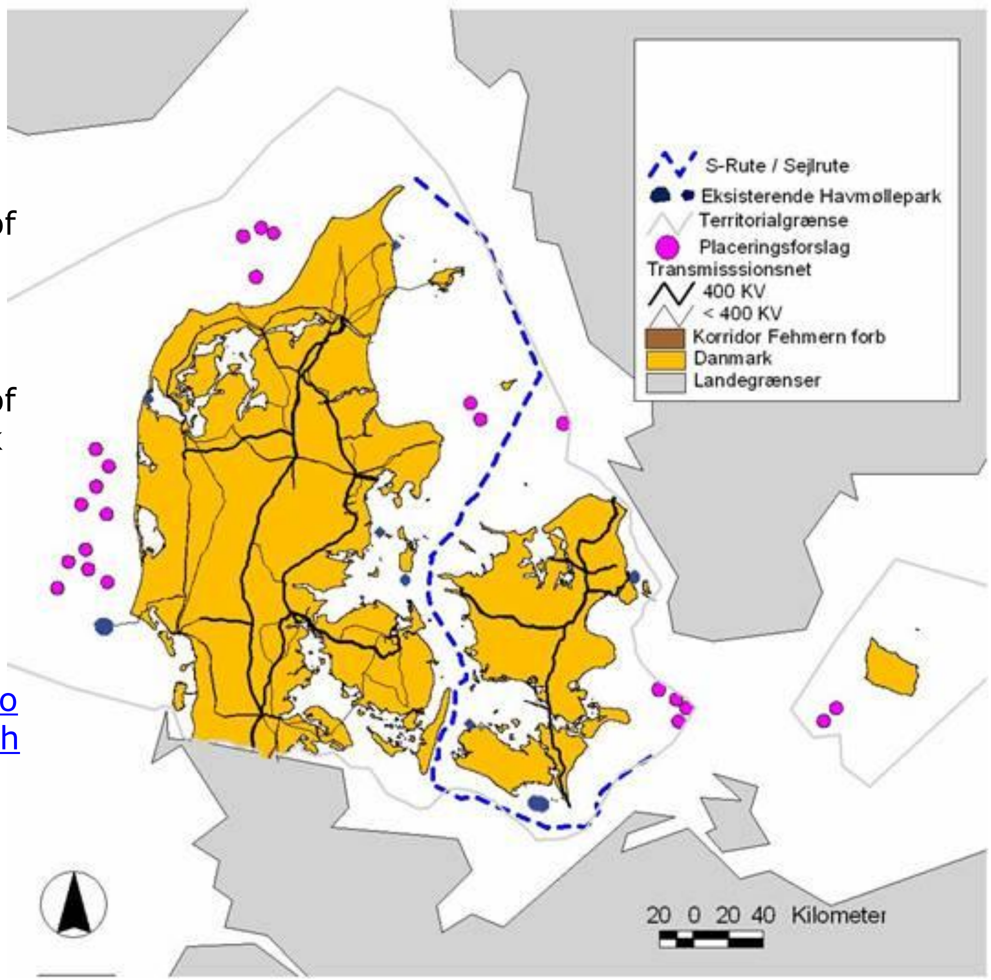


Existing wind turbines in Denmark



Future Danish offshore sites

- Report on future Offshore sites
- Update of action plan from 1997
- 23 Sites each 44 km2 for a capacity of 4600 MW Wind Power
- Production 18 TWh, or just over 8% of total energy consumption in Denmark or approximately 50% of Danish electricity consumption
- http://www.ens.dk/graphics/Publikationer/Havvindmoeller/Fremtidens_%20havvindm_UKsummery_aug07.pdf



Denmark
demonstration country for wind energy

National targets and policy

25% of electricity from wind energy today
50% of electricity from wind energy by 2020 (in new government programme)

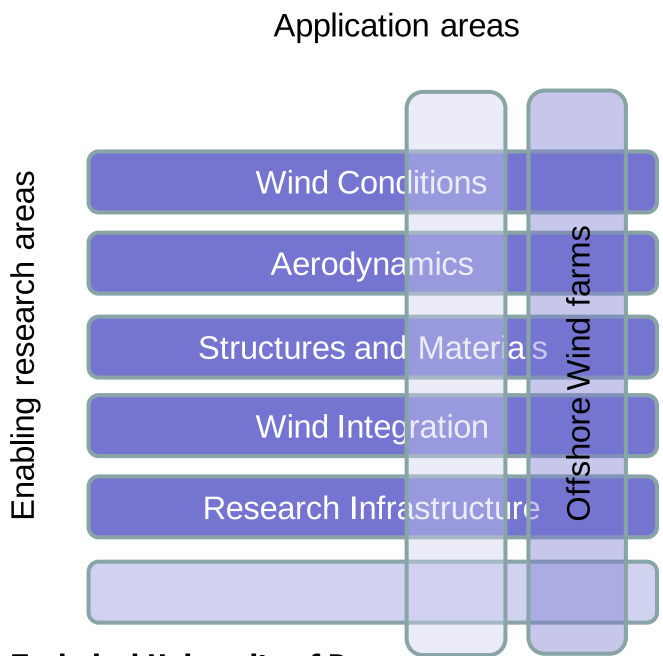
Innovation Partnership between Research and Industry (MegaVind)

- world leading centre of competence in wind power
- **...** to provide the most effective wind power and wind power plants – that ensure the best possible integration of wind power …

In global partnerships
such as e.g. TPWIND and EERA in Europe

The EERA Joint Programme on Wind Energy aims at accelerating the realization of the EU SET-plan goals and to provide added value through:

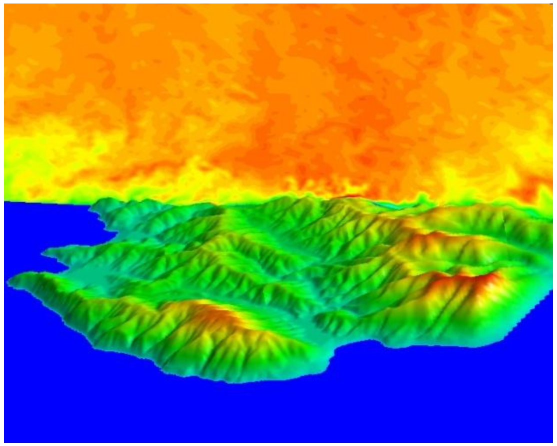
- Strategic leadership of the underpinning research
- Joint prioritisation of research tasks and infrastructure
- Alignment of European and national research efforts
- Coordination with industry, and
- Sharing of knowledge and research infrastructure.

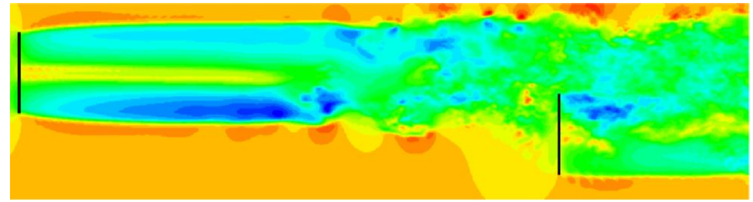


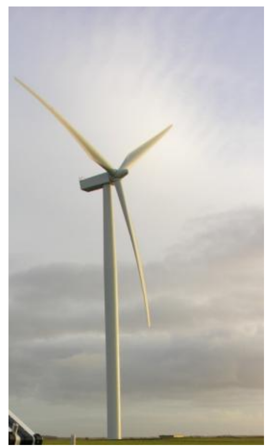
R&D - Aeroelastic Design Methods

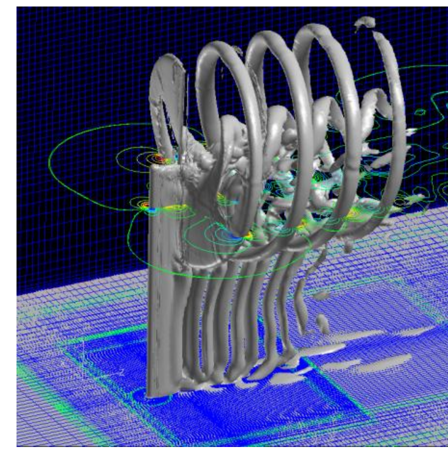
- Aerodynamic and aeroacoustic design
- Aero-servo-elastic design
- Wind farm design
- Innovative wind turbine design

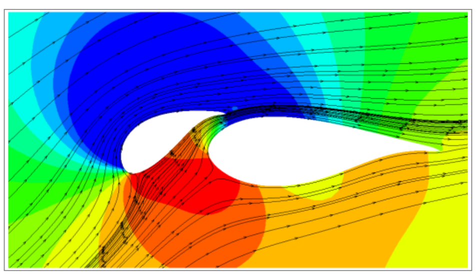
Advanced Wind Turbine Aerodynamics - modelling and experimental validation

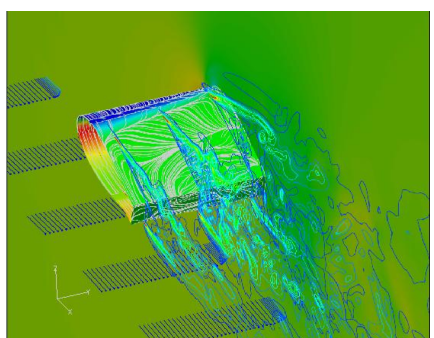


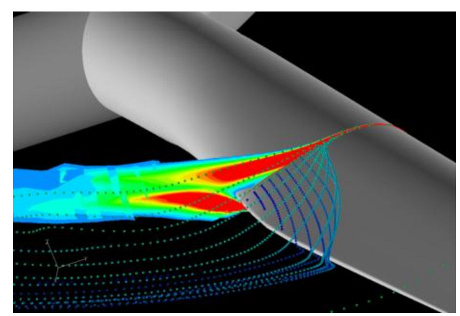








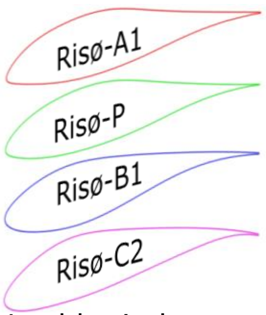




Airfoil and blade design

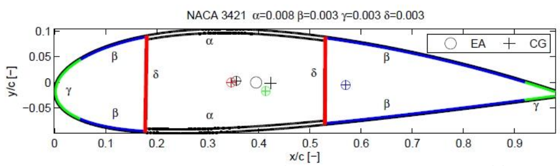
Traditional airfoils and blades

Aerodynamics



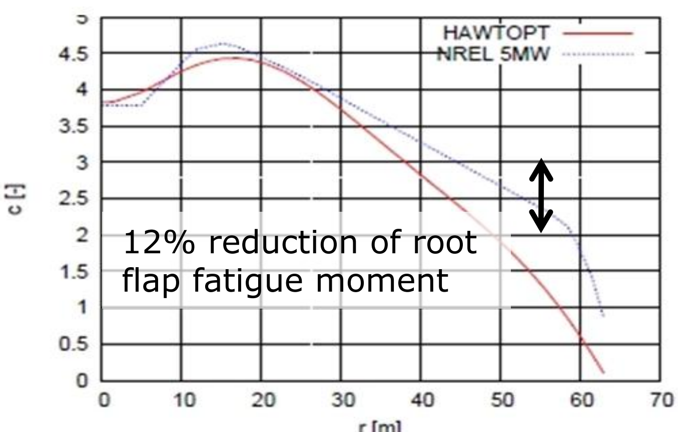
Used by industry

Structure



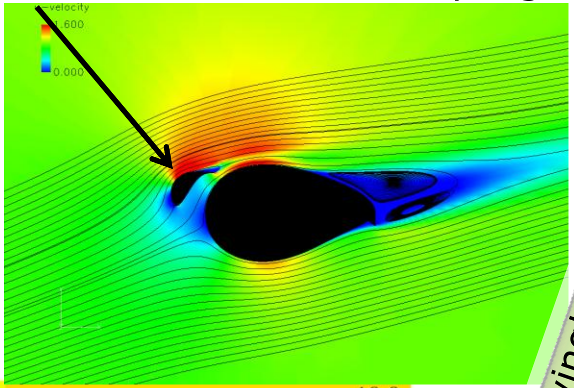
Easy estimate of mass and stiffness

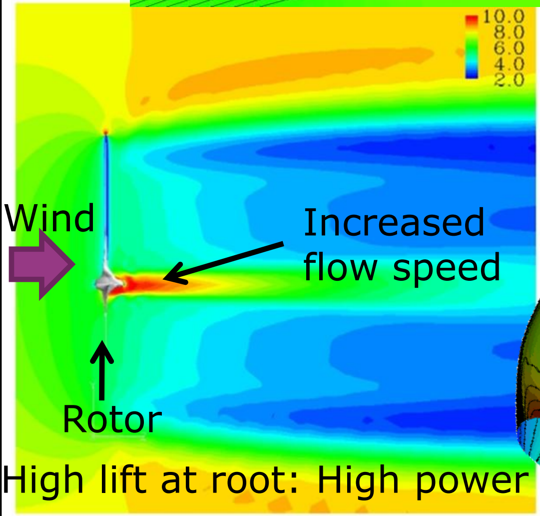
Slender blade reduce loads
High lift airfoils are needed

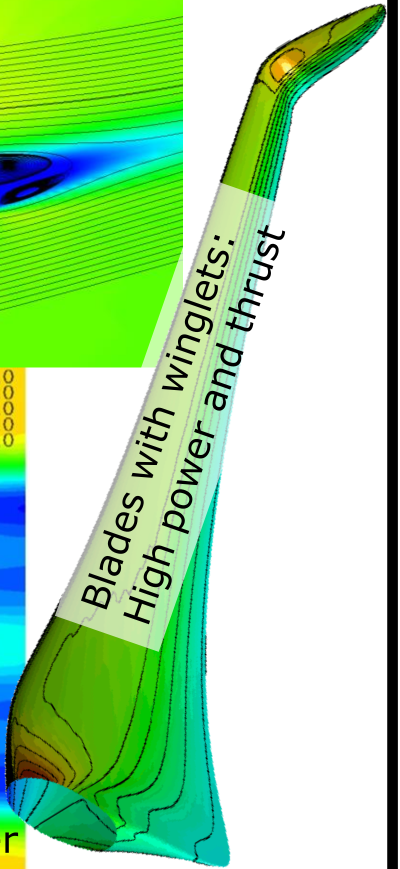


Advanced airfoils and blades

Slats on thick airfoils: Very high lift

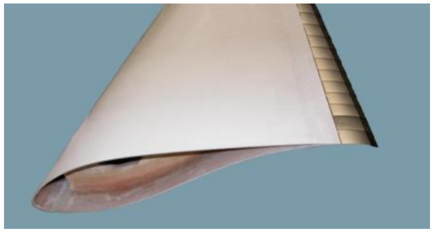




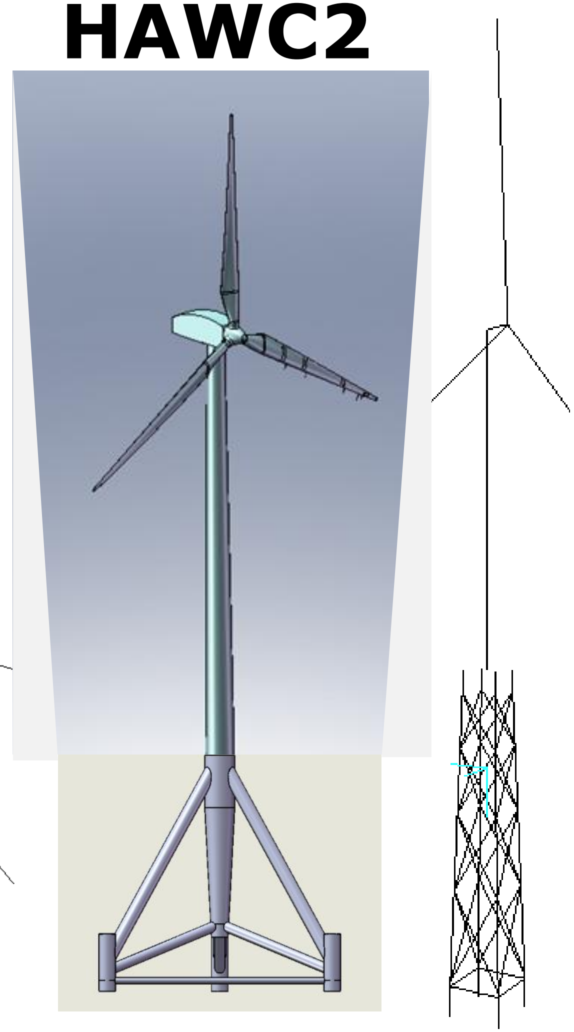


Aero-servo-hydro-elastic simulation platform

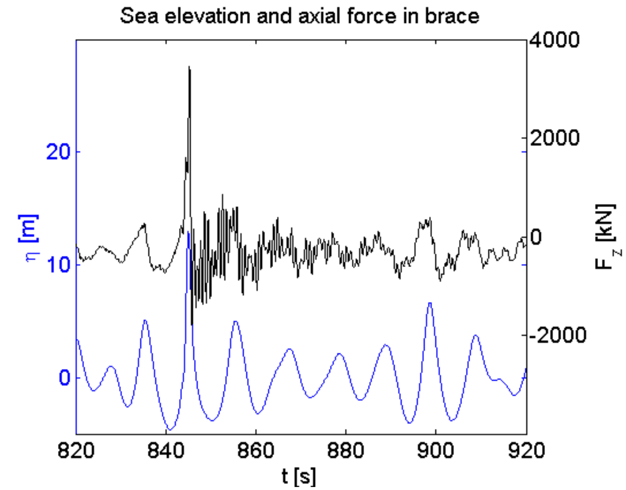
Advanced control, e.g. trailing edge flap



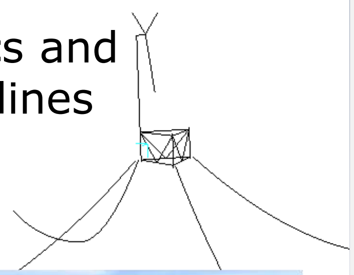
HAWC2



"Ringing" due to large non-linear waves



Hydrodynamics and dyn. mooring lines



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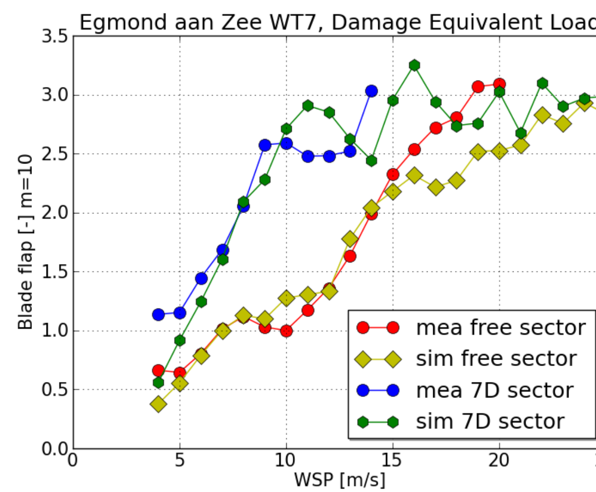
Blade load comp. in free and wake conditions

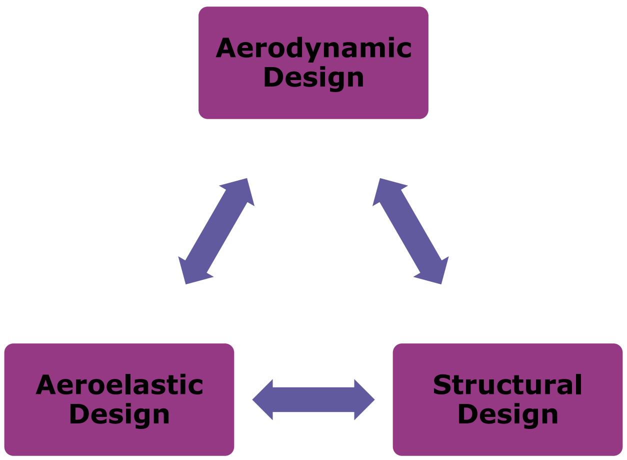


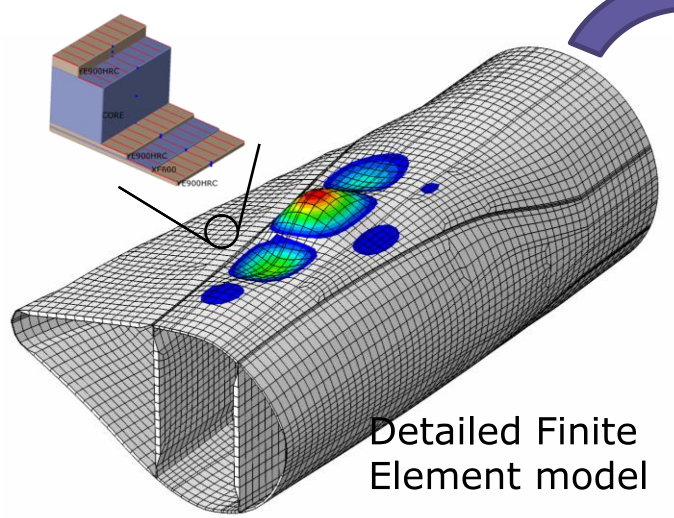
R&D - Wind Turbine Structures

- Load and safety
- Structural design of blades
- Wind turbine structures and components
- Multi-disciplinary optimization

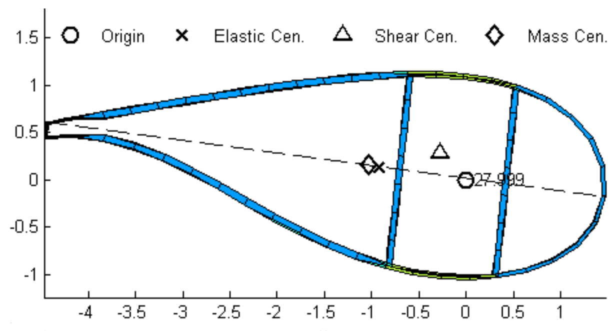
The Light Rotor Project

- Future very large rotors (P=10MW, R=90m) require strong emphasis on lightweight design.
  - →Larger relative airfoil thickness
  - →Blade sweep
  - →Optimized structural design
- The project develops an integrated design method incorporating aerodynamic design, aeroelastic design and structural design.
- Topology optimization is used to find innovative structural concepts.
- A very light blade for a 10MW turbine is designed.

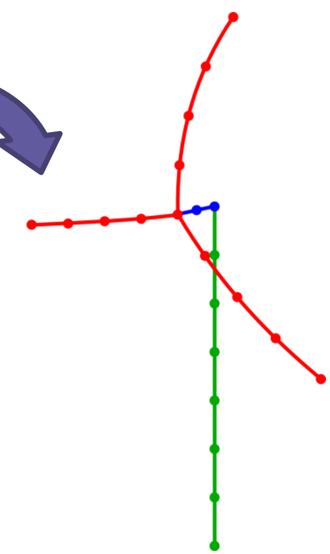




Detailed Finite Element model



Beam Cross Section Analysis Software (BECAS), taking into account all couplings

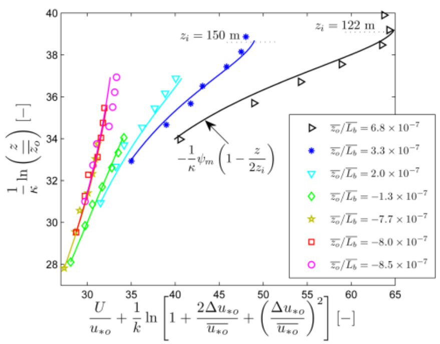


Aeroelastic Analysis (HAWC2)

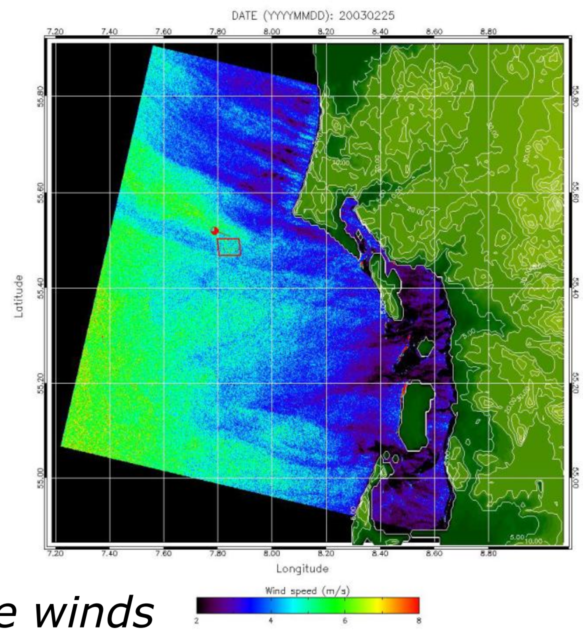
R&D - Offshore Wind Energy

- Marine wind, wave and current conditions
- Wakes in offshore wind turbine farms
- Project development, operation and maintenance
- Integrated design tools
- New concepts

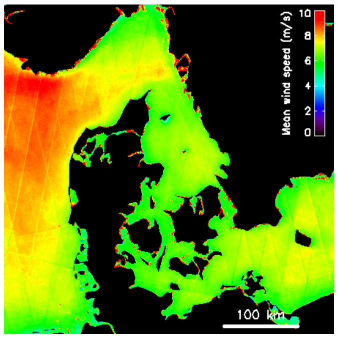
Offshore Wind Conditions



Lidar wind data and model from Horn's Reef offshore

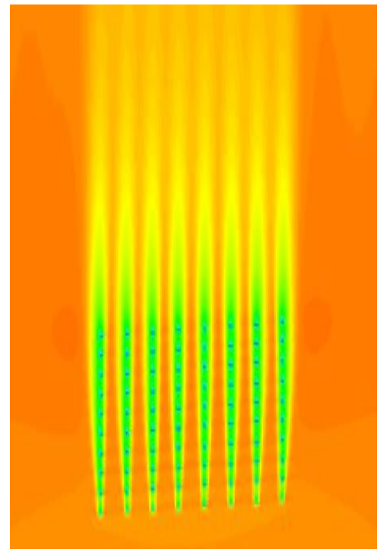


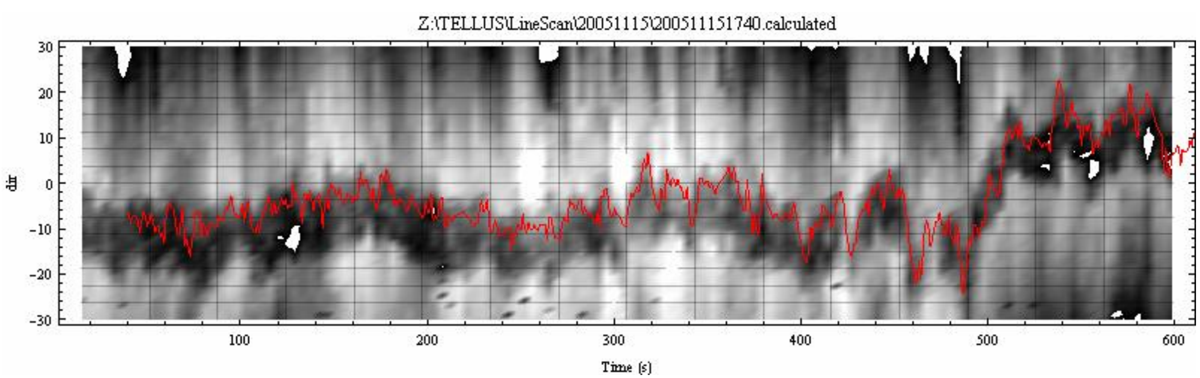
Satellite winds showing the wake at Horn Reef wind farm. Mean wind speed map using satellite Envisat ASAR.



- Ocean winds
- Lidar observations and modelling
- Wind resource mapping using satellite data
- Mesoscale modelling
- Meteorological mast observations
- Wind farms shadow effect
- Satellite observations

Offshore Wind Farms





Dynamic wake meander motion

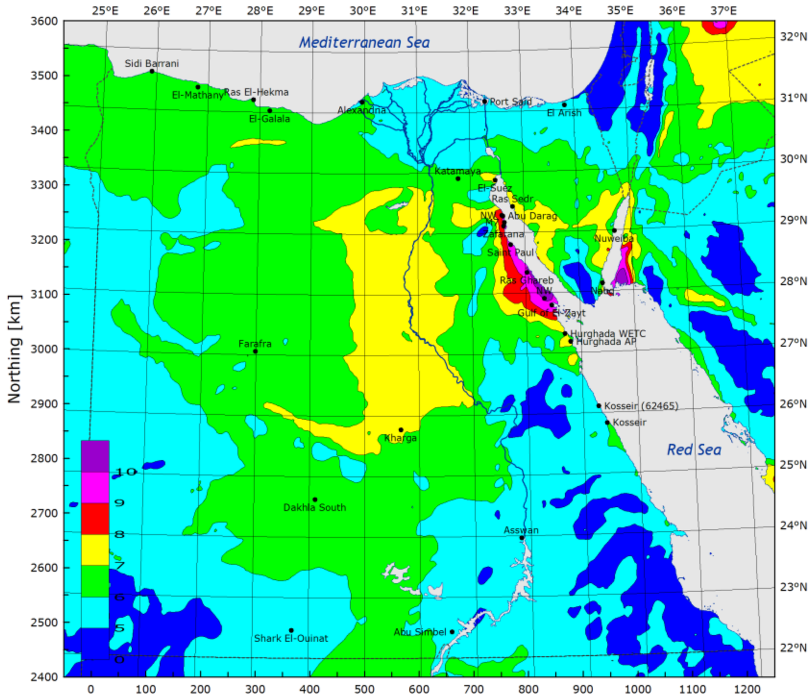
- Wind turbines wake effect
- Multiscale CFD turbulence models (ABL + wake)
- Wind farm data analysis
- Influence of atmospheric stability
- Dynamic wake meander model
- Wind farms shadow effect
- Micro-mesoscale interaction
- Wind farm layout optimization

R&D – Wind Power Meteorology

- Atmospheric flow modelling
- Methods for atmospheric model verification
- Fundamental atmospheric processes
- Determination of external wind conditions for siting and design of wind turbines

Wind Atlas Method and tools

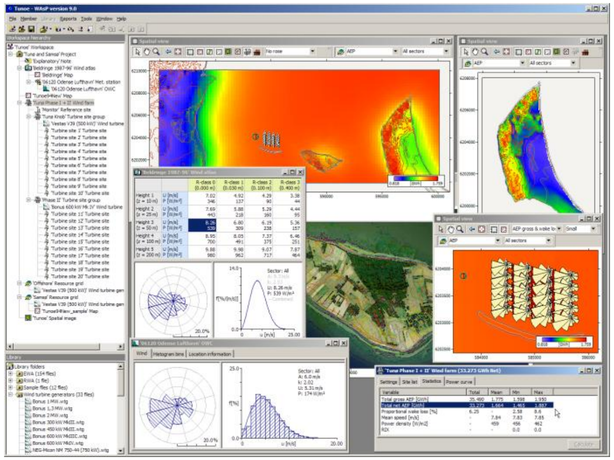
Wind Atlas Denmark (1981)
Wind Atlas Europe (1989)
Wind Atlas for Egypt (2006)



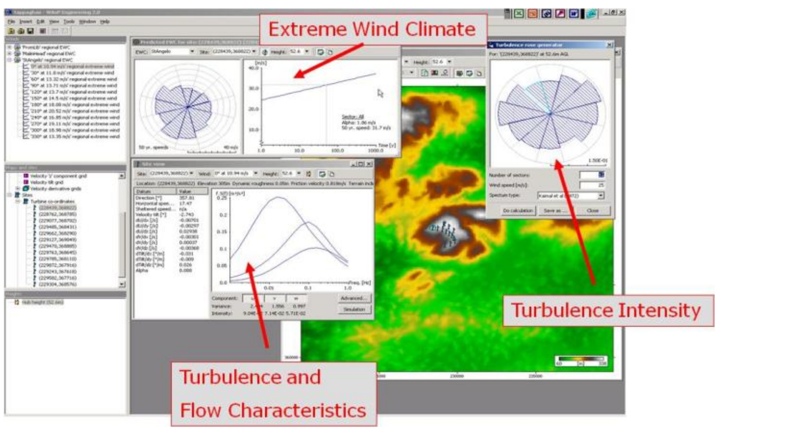
Wind Atlas India (2008)
Wind Atlas NE China (2010)
Wind Atlas South Africa (2011)
Global WA

Risø DTU, Technical University of Denmark

WAsP – wind resource assessment



WAsP Engineering – design conditions

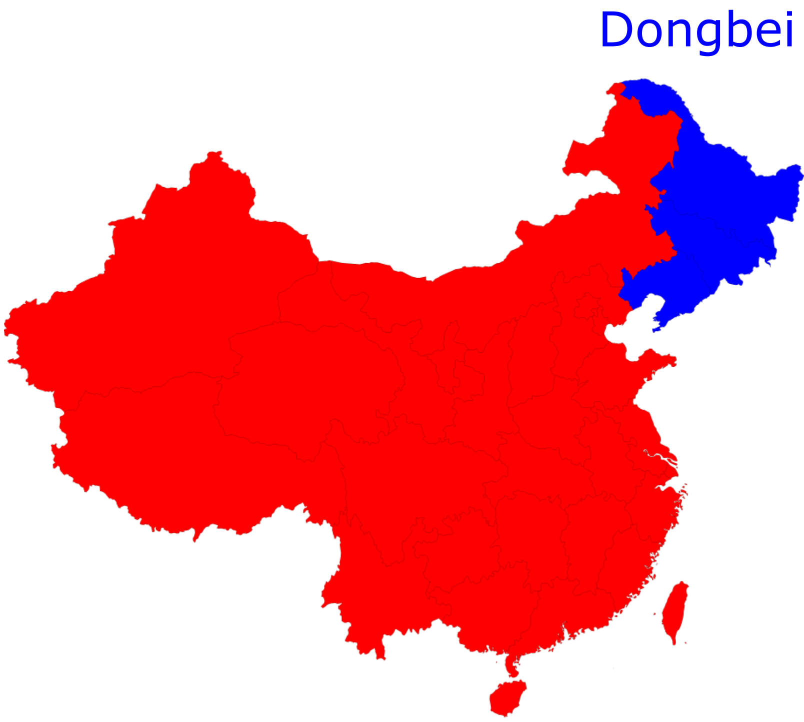


Wind Atlas in N.E. China

- Part of the Sino-Danish Wind Energy Development Programme (WED) 2008-2010; co-funded by China (MOFCOM and NDRC) and Denmark (Ministry of Foreign Affairs)

- Wind resource assessment in Dongbei (NE China) Research & Development in
  - measurement practices
  - observational and numerical wind atlas methodologies
  - verification and uncertainties
  - application aspects for wind energy planning and project preparation

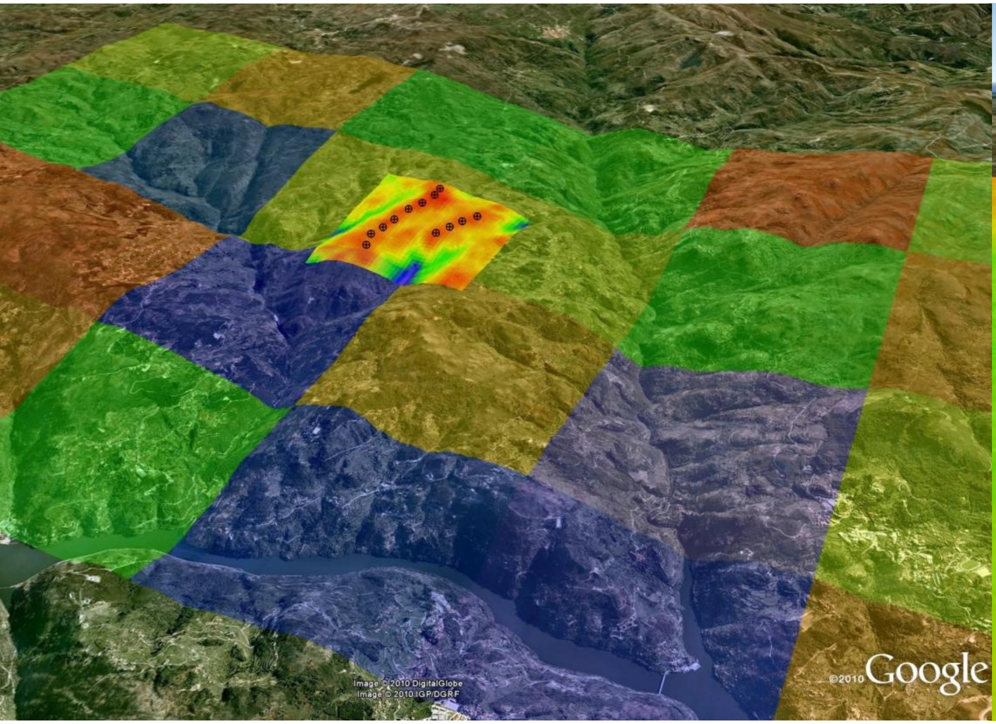
- Partners:
  - China Meteorological Administration (CMA)
  - Risø DTU, Technical University of Denmark

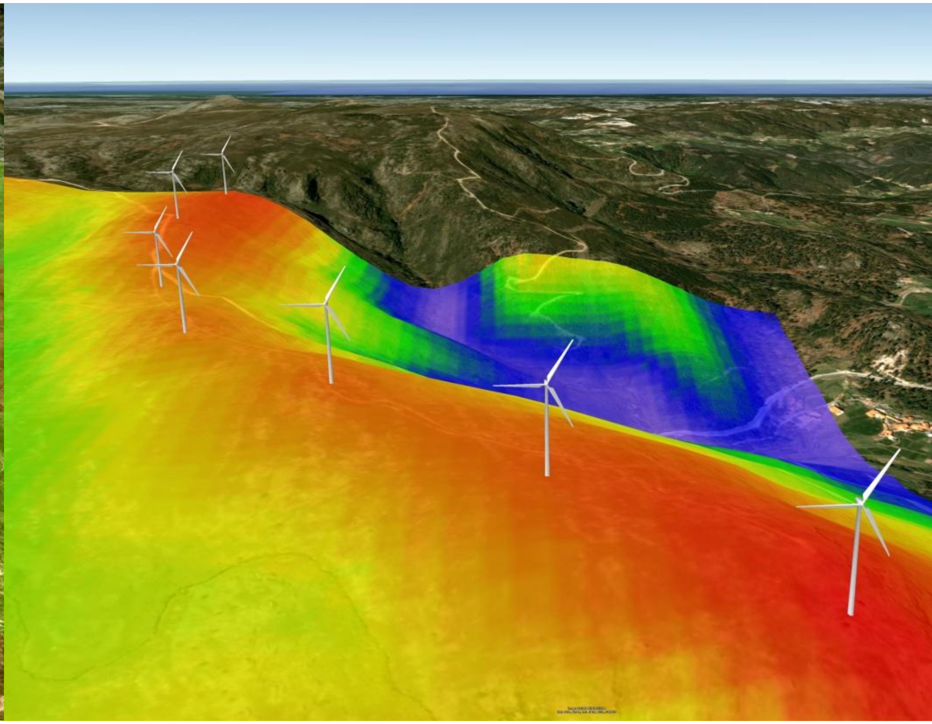


Application

Results of the “Meso-Scale and Micro-Scale Modelling in China” project, is available in public domain, containing description of the Wind Atlas Method and how to apply the Numerical Wind Atlas

http://www.dwed.org.cn/





The TALL wind project - Long term studies of the wind profile up to 1 km

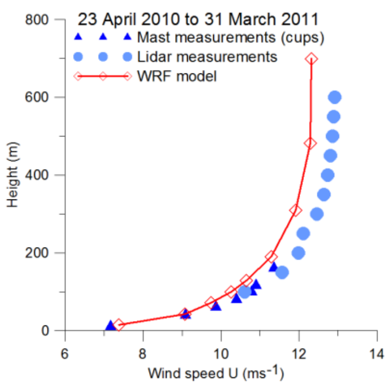
Wind Lidar Measurements has been carried out at Høvsøre for one year, presently the lidar is operating in Hamburg and in 2012 will be off-shore

From 100 m to 1 km
with the lidar

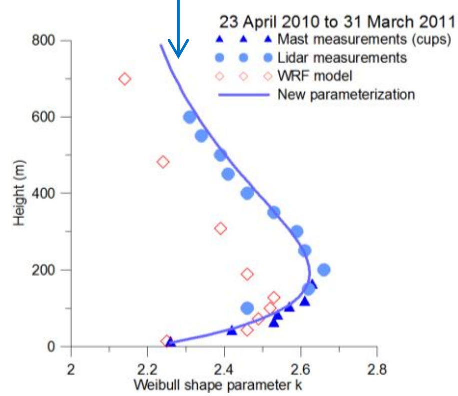
From 10 to 116 m
at the mast

New parametrization
for the shape parameter in the
Weibull distribution

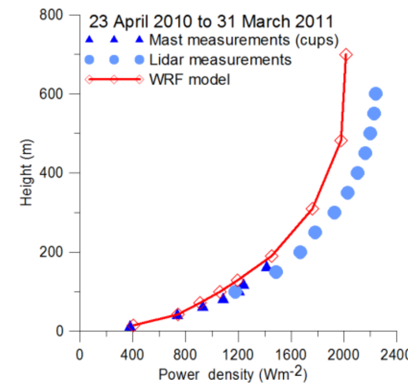
Long term wind speed



Long term shape parameter



Long term wind power density



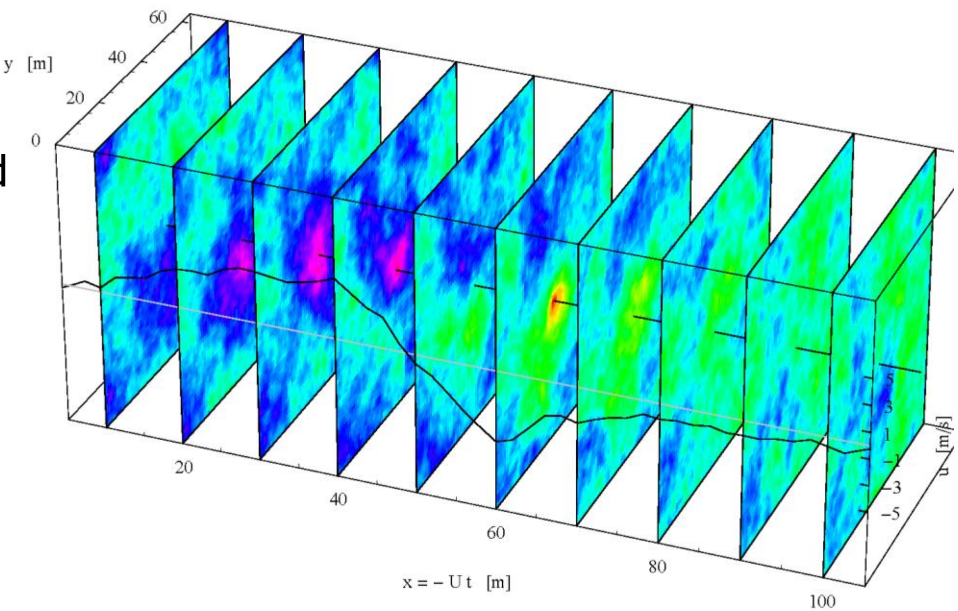
Turbulence structure and inflow simulation

The Mann 3D spectral tensor model is used

- by leading wind turbine manufacturers for load calculation
- in the IEC 41600-12 standard on conditions for WTs
- to understand how lidars measure atmospheric turbulence
- as inflow in the EllipSys3D to speed up calculations
- to embed extreme gusts in turbulence fields

The simulation model in freely available on www.wasp.dk

Current work:
Extend model to include atmospheric stability



R&D - Test and measurements

Risø Test Stations – Prototype Testing

5 test beds

< 165 m

< 8 MW

Spacing 300 m

7 test beds

< 250 m

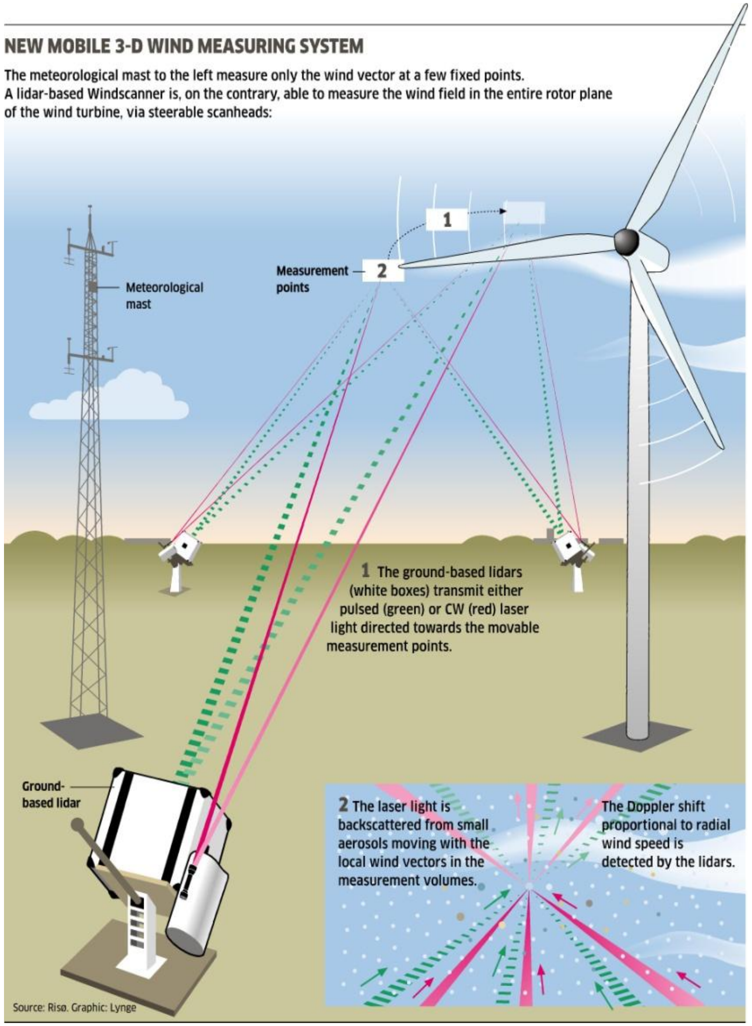
< 16 MW

Spacing 600 m

Blade test facility

Innovative load introduction tested

Windscanner.DK



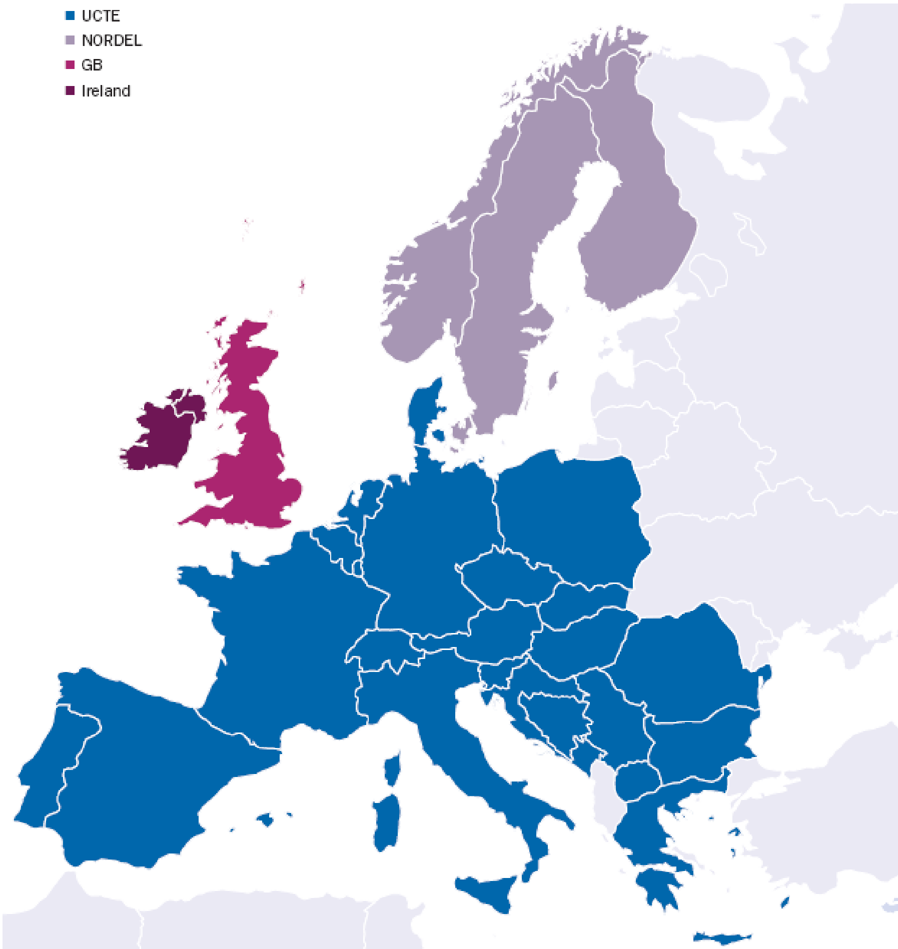
Lidar-based wind and turbulence measurements for research, siting and control

R&D - Wind power integration and control

- Wind power plants in the power system
- Variability, prediction and predictability of wind power
- Integrated design and control of wind turbines and wind farms
- Policies and strategies for wind energy research and innovation

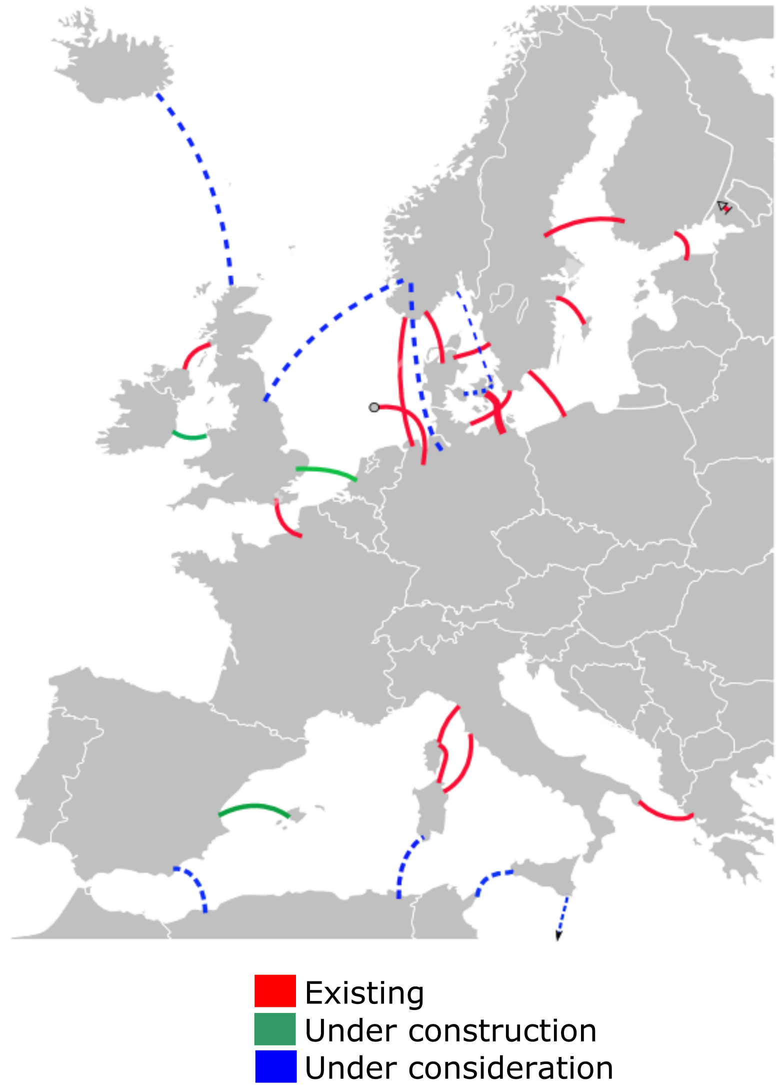
Wind integration: European perspective

European Synchronous Zones



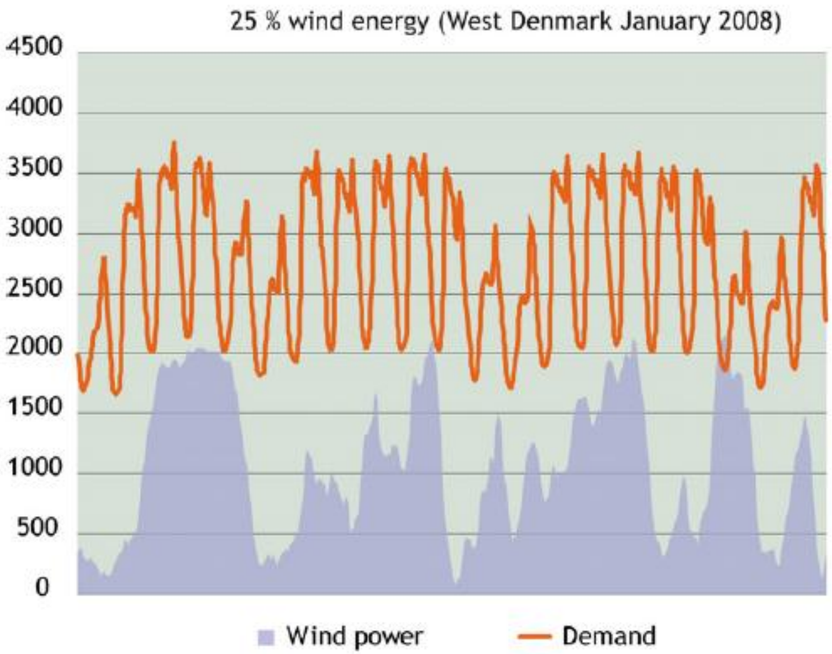
Source: EWEA

European DC interconnectors

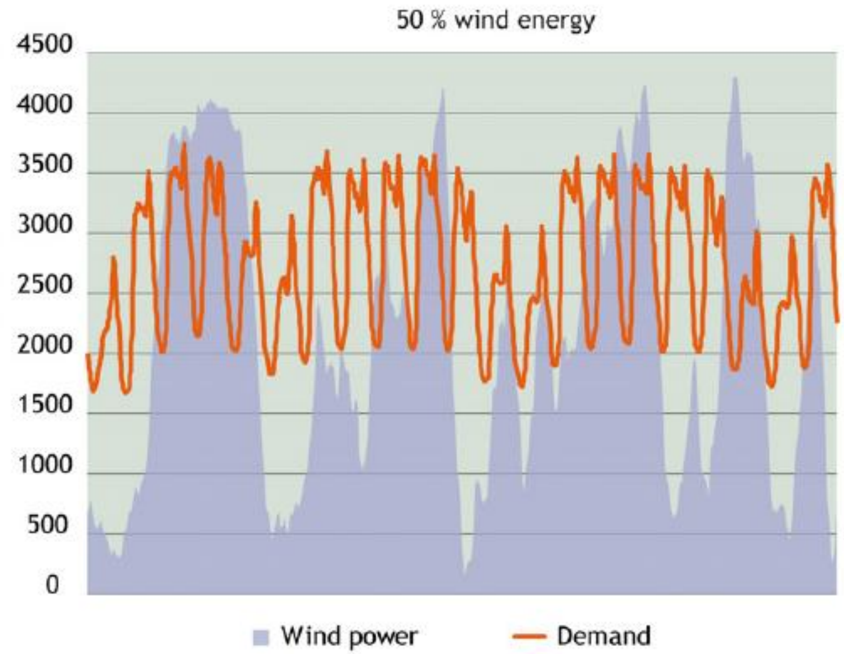


Wind integration: The Danish Target

2008



2025



- Approximately 20% of electricity consumption met by wind power – annual average
- Around 3GW installed wind power capacity
- For a few hours in a year wind power covers the entire Danish demand

- 50% of electricity consumption to be met by wind power – annual average
- Around 6GW installed wind power capacity
- Wind power production will often exceed the Danish demand

Source: Energinet.dk - EcoGrid

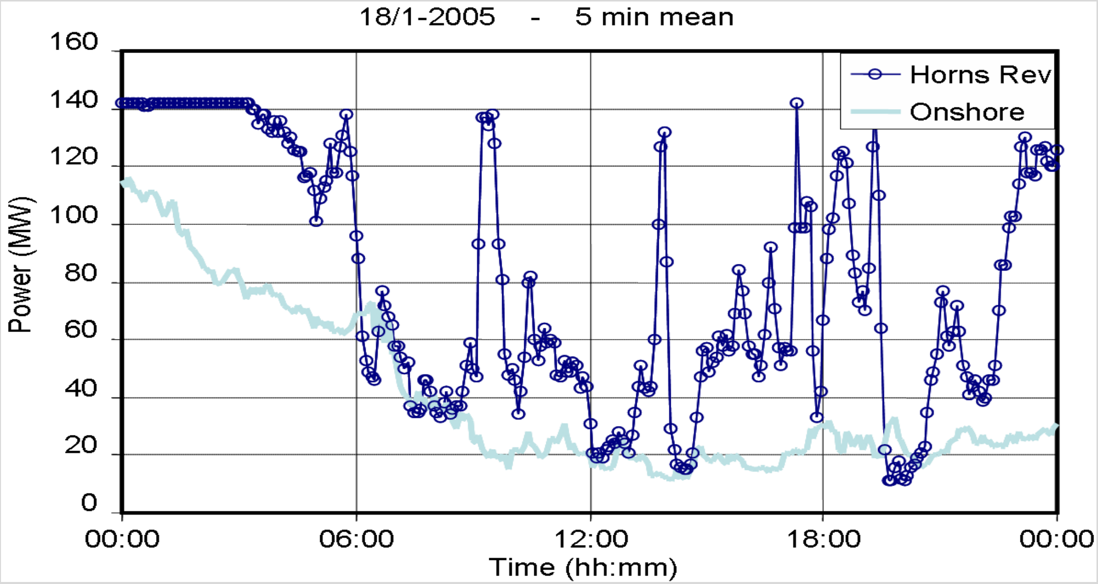
Wind power variability and prediction

Danish research efforts have as goal:

- to improve power system and wind power plant functionality
- to seek solutions to enable integration of large amounts of wind power
- to assure the security and reliability of power supply in power systems with large amounts of wind power

Relevance for planning, design and operation !

Example of Horns Rev wind farm



Source: DONG Energy and Vattenfall

Power fluctuations

- offshore more than onshore
- power gradients of 15MW/min
- from 0 to 160MW in 10-15 min**!**

Possible impact on:

- system power balancing
- deviations of the power exchanges between neighbouring countries

Wind integration: The Challenges

Some challenges

- Balancing production and consumption
- Power transfer from production to consumers
- Coping with faults
- Coping with variability
- Requirements for ancillary services

Some promising solutions

- Enhancing grid infrastructure
- Wind power plant capabilities
- Low voltage ride through
- Better modelling tools
- Better prediction tools
- More flexibility and controllability
- Smart grids and storage

Prediction

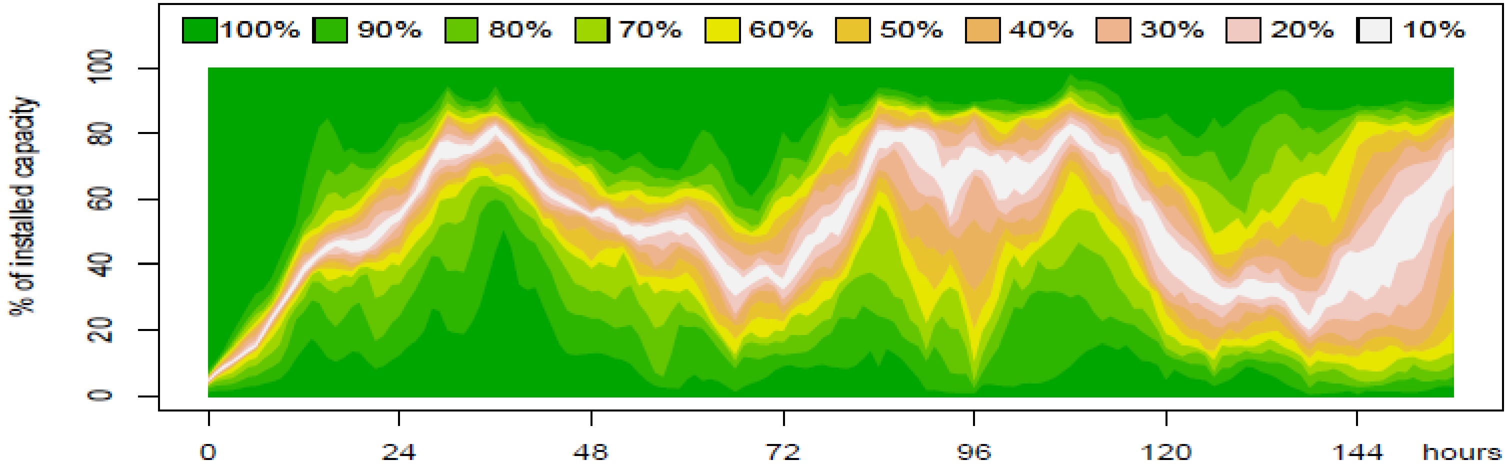
ANEMOS SafeWind (EU FP7)

- **OBJECTIVES**

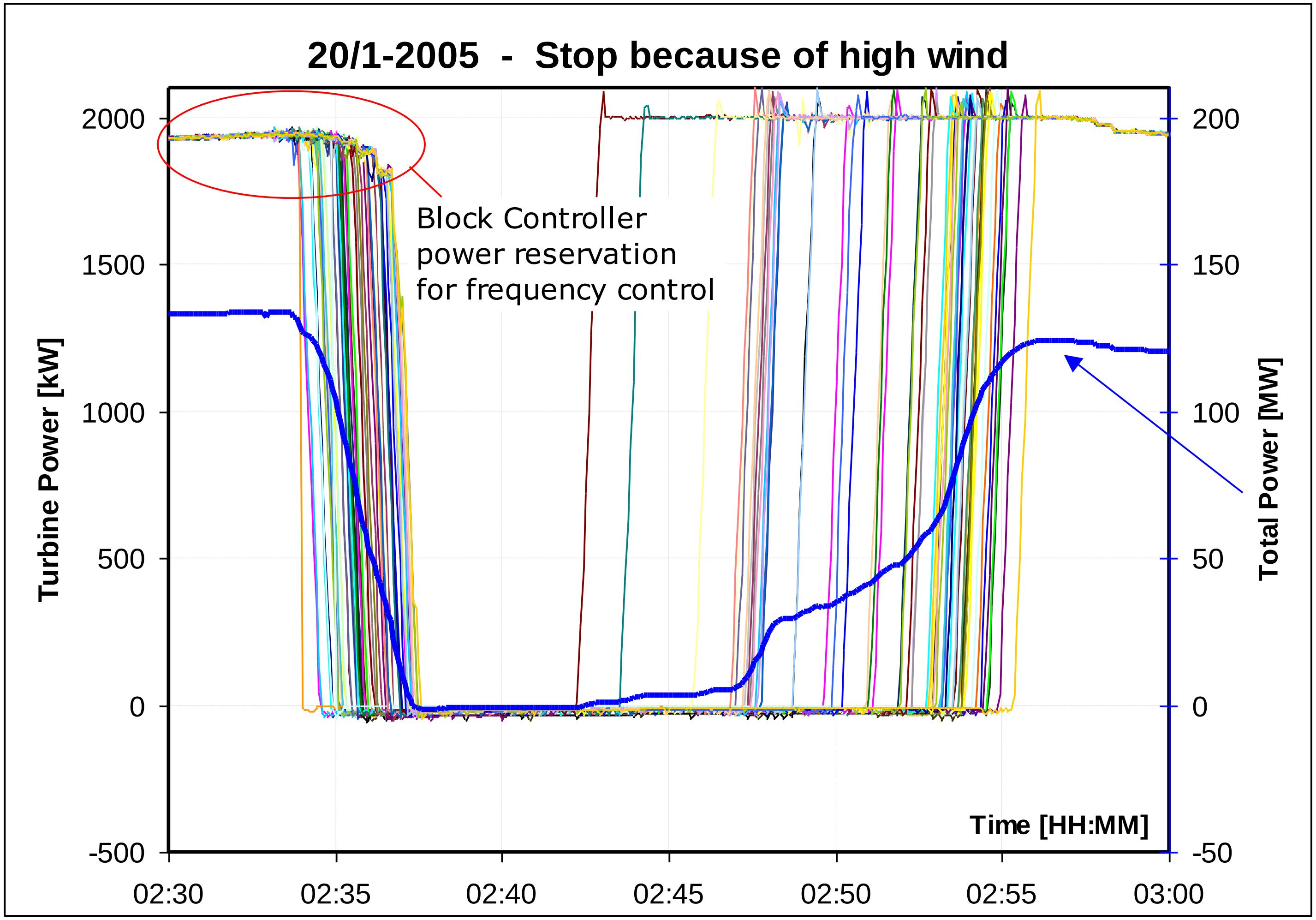
To improve wind predictability with focus on **extremes** at various **temporal** scales (5 min to days ahead) and at various **spatial** scales (gusts, thunderstorms and fronts)

- **RESULTS**

Risø DTU developed a variability forecast for the time scale of variations for the next day or two. Risø DTU also improved data assimilation into the WRF model, using wind farm data directly. For the sister project ANEMOS.plus, Risø DTU implemented the WILMAR model to test probabilistic scheduling for Ireland.



Storm passages

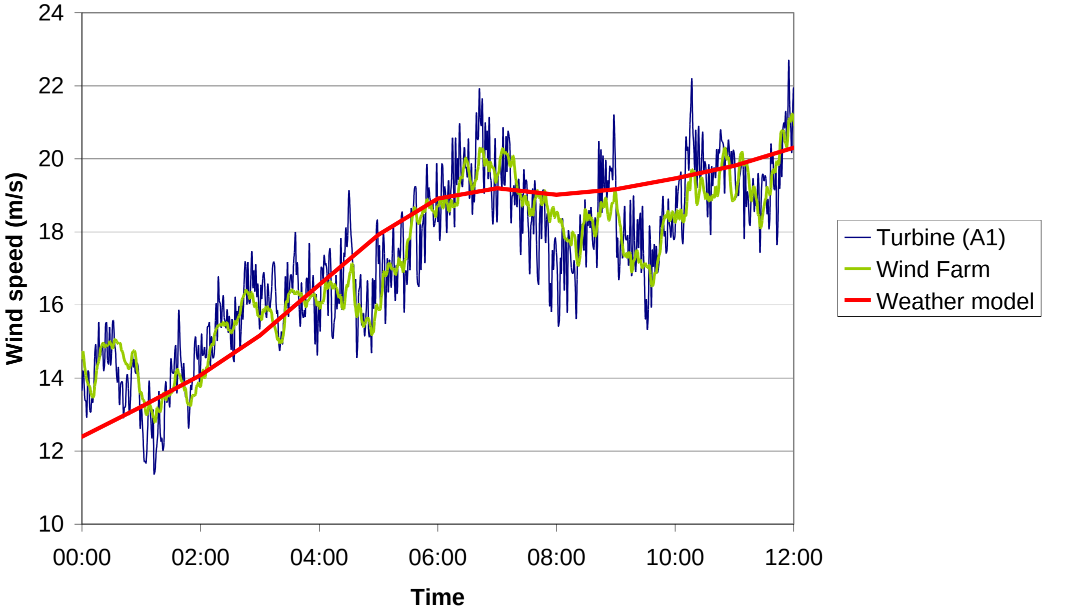


Modelling of wind power fluctuations

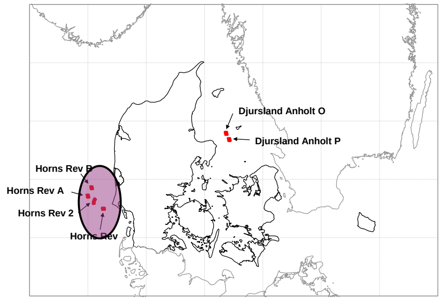
- Risø DTU CorWind (correlated wind speeds) model
  - Model wind speeds at each wind turbine
  - Combines two time scales
    - Slow time scale from weather models (too slow for power system integration studies)
    - Faster fluctuations from stochastic model

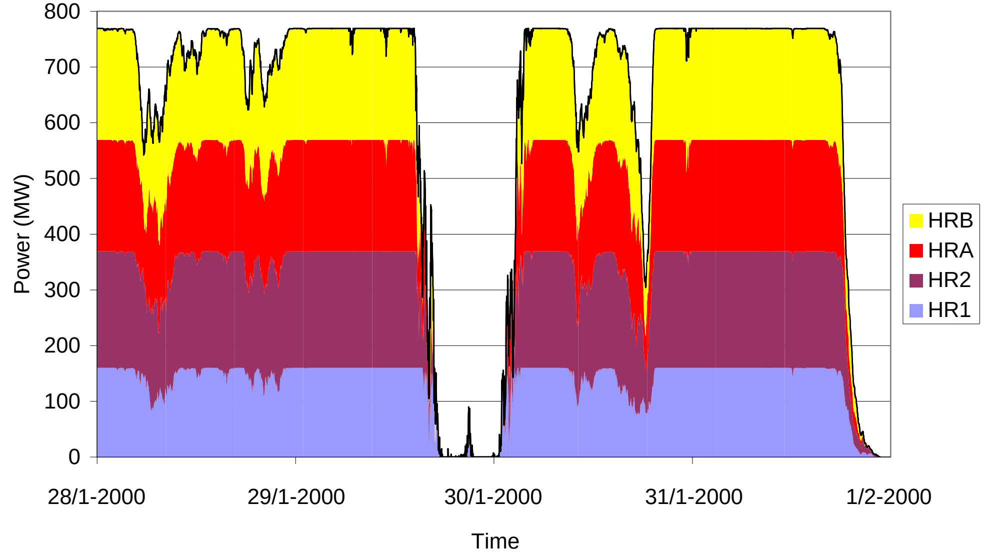
- Model validated (Horns Rev and Nysted measurements)

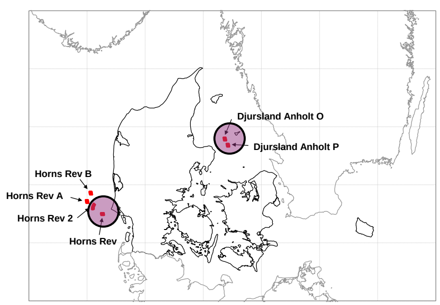
- Model applications:
  - Power system planning incl. reserve requirements
  - Special focus of storm situations (with 2GW offshore wind power on Danish west coast)

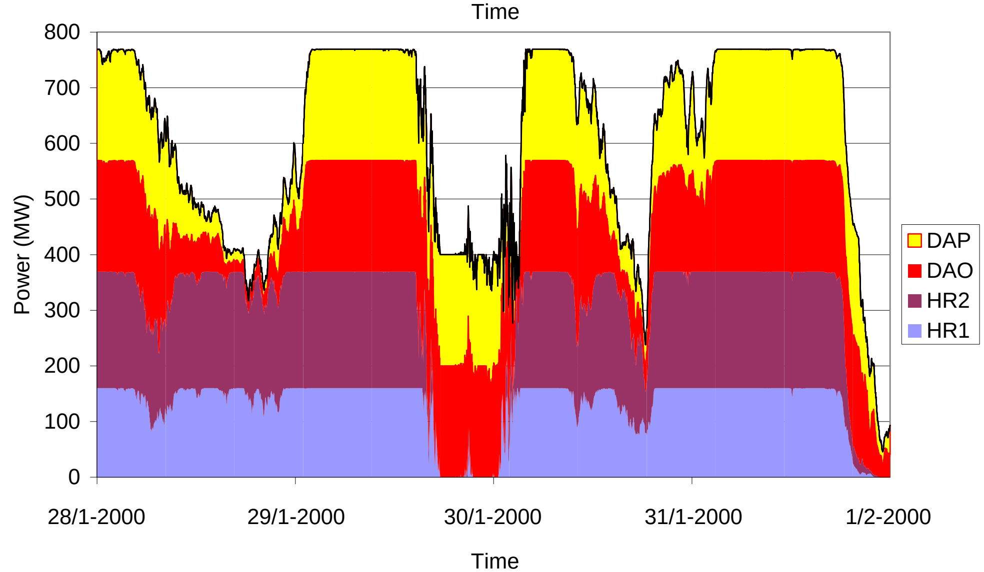


Power fluctuations – the two study cases









Twenties
Transmitting wind

SEVENTH FRAMEWORK PROGRAMME

EUROPEAN COMMISION

Consortium and budget

- ✓ 10 European Member States
- ✓ 1 Associated Country

United Kingdom (2)
AREVA T&D
UNIVERSITY OF STRATHCLYDE

France (2)
RTE
EDF

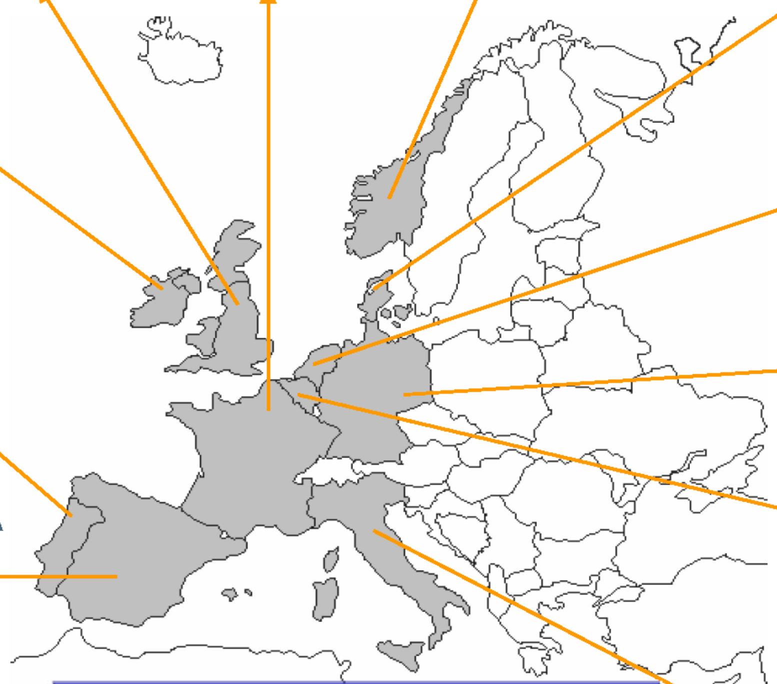
Norway
SINTEF

Denmark (3)
DONG ENERGY
ENERGINET
RISO DTU

Ireland
UCD

Portugal
INESC-PORTO

The Netherlands
TENNET



Germany (3)
Fraunhofer IWES
50 Hz
SIEMENS Wind Power

Spain (5)
RED ELECTRICA DE ESPAÑA
IBERDROLA RENOVABLES
ITT COMILLAS
GAMESA
ABB S.A

Belgium (6)
ELIA System Operator
EWEA
CORESO
UNIVERSITY LIEGE
UNIVERSITY LEUVEN-ELECTA
UNIVERSITE LIBRE BRUXELLES

Italy
ERSE

Total budget: 56,8 M€
EU contribution: 31,8 M€

Project objectives

Task force 1: What are the valuable contributions that intermittent generation and flexible load can bring to system services?

Task force 2: What should the network operators implement to allow for off-shore wind development?

Task force 3: How to give more flexibility to the transmission grid?

→ 6 high level demonstration objectives

Overall: How scalable and replicable are the results within the entire pan-European electricity system?

→ 2 replication objectives

→ 1 dissemination objective

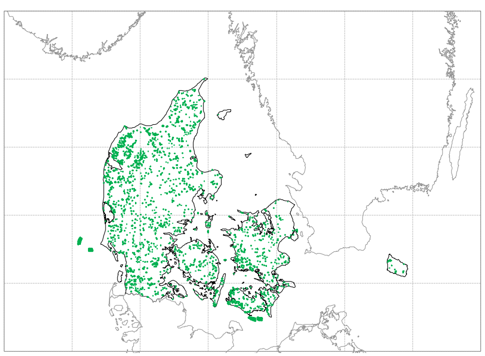
TWENTIES – WP16.2 (EU FP7)

OBJECTIVES

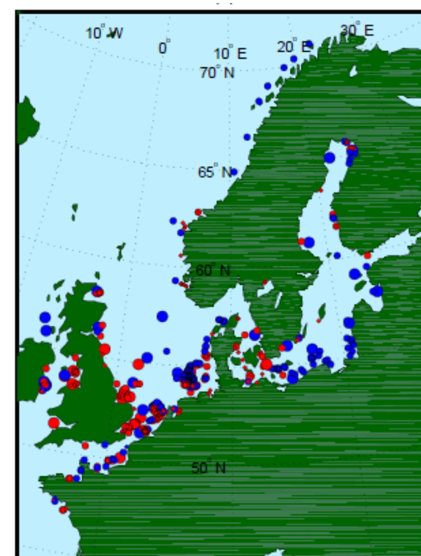
- Study power system balancing and reserve requirements with **massive offshore wind power**
- Special focus on sudden loss of wind power due to storm passages

RESULTS

- Time series of wind power generation and forecast errors in 2020 and 2030 – development and use of CorWind
- **Quantification of reserve requirements**



from large scale onshore to massive scale offshore



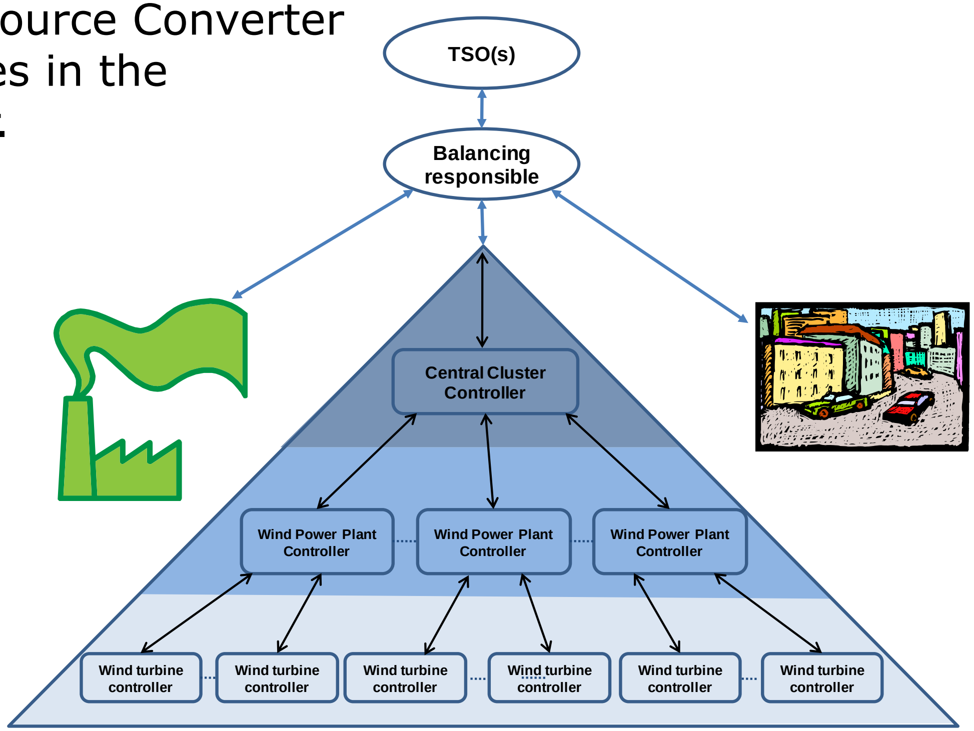
red: 2020
blue: 2030

DC grids for integration of large scale wind power *(OffshoreDC)*

Overall objective:
To develop and apply the Voltage Source Converter (VSC) based HVDC grid technologies in the deployment of offshore wind power.

Partners:

- Risø DTU – VES
- Vestas Technology R&D
- ABB
- Chalmers University
- SINTEF
- DTU- Elektro
- DONG Energy
- EnergiNet.dk
- VTT
- Statnett



Cluster control:
Communication and control in clusters of wind power plants connected to HVDC offshore grids *(control system architecture, allocation of control tasks, communication protocol)*

Modelling of wind turbines and wind farms

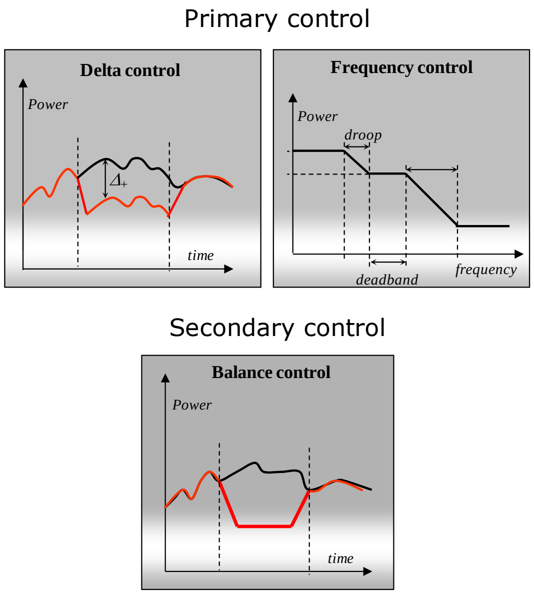
Large wind farms in the power system

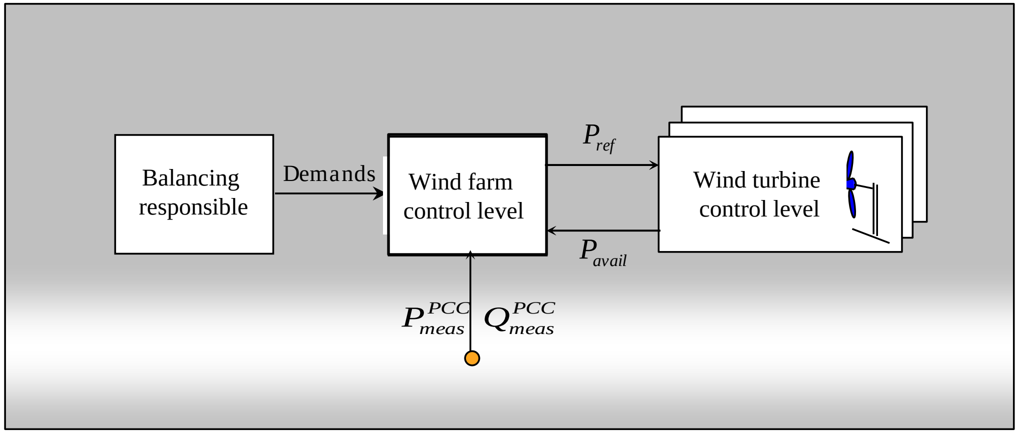
- Dynamic wind turbine and wind farm models
- Power system studies (DIgSILENT, PSS/E, SIMPOW, PSCAD/EMTDC)

Wind farm concepts and control:
- Active stall wind turbines
- Doubly-fed induction wind turbines
- PMSG full converter wind turbines

Grid types:
- large and strong
- small and isolated

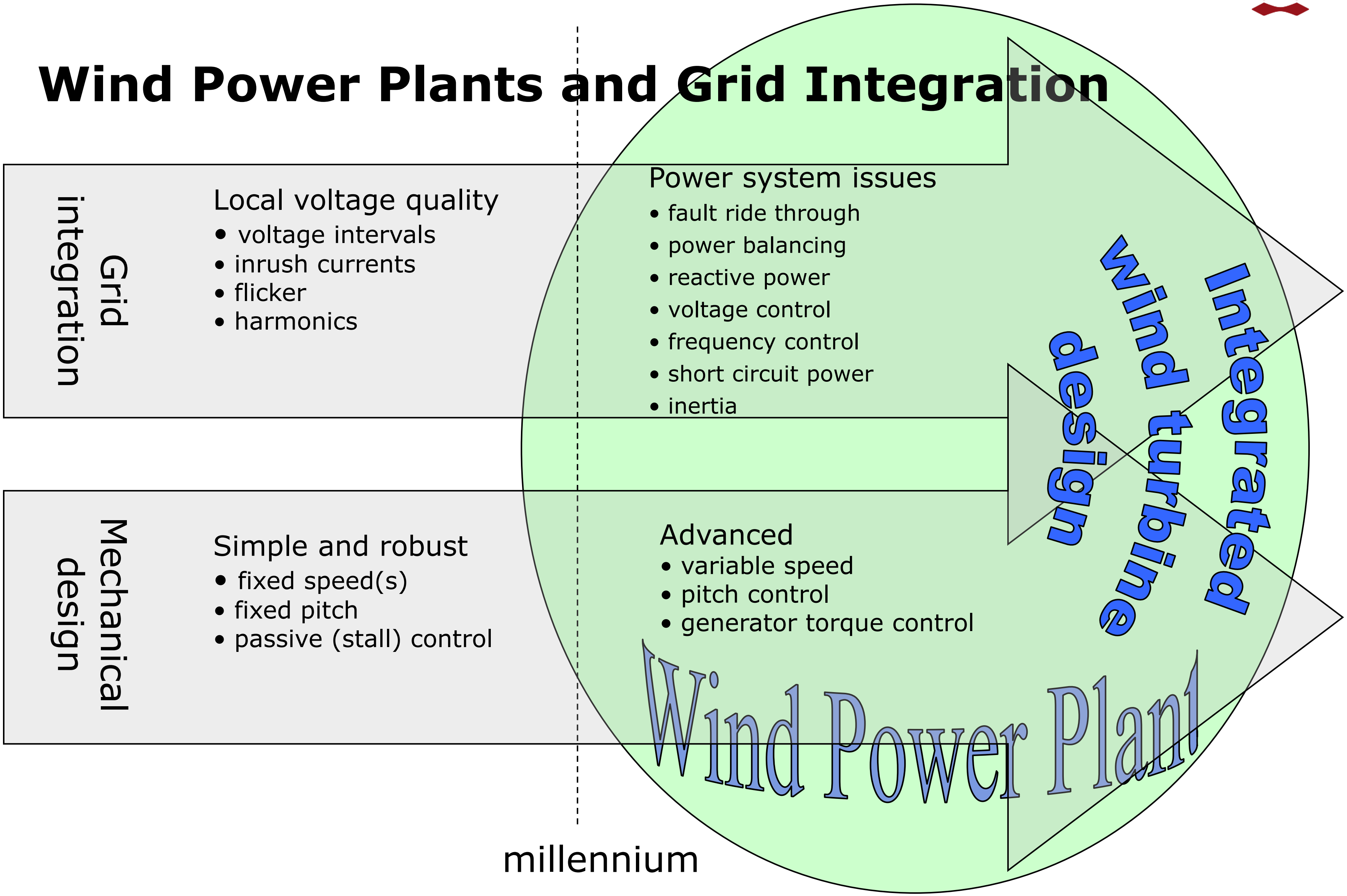
Modelling approach:
- individual
- aggregated





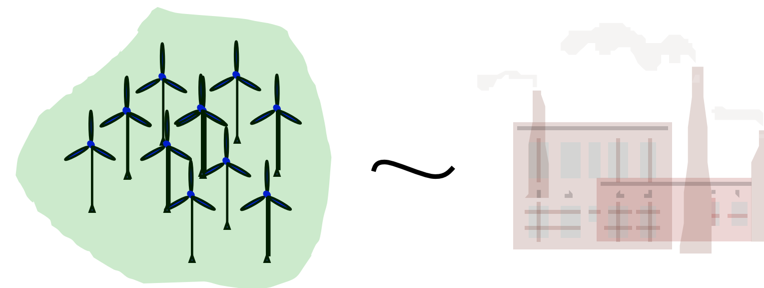
Wind farm controller's goal is to meet grid integration challenges !

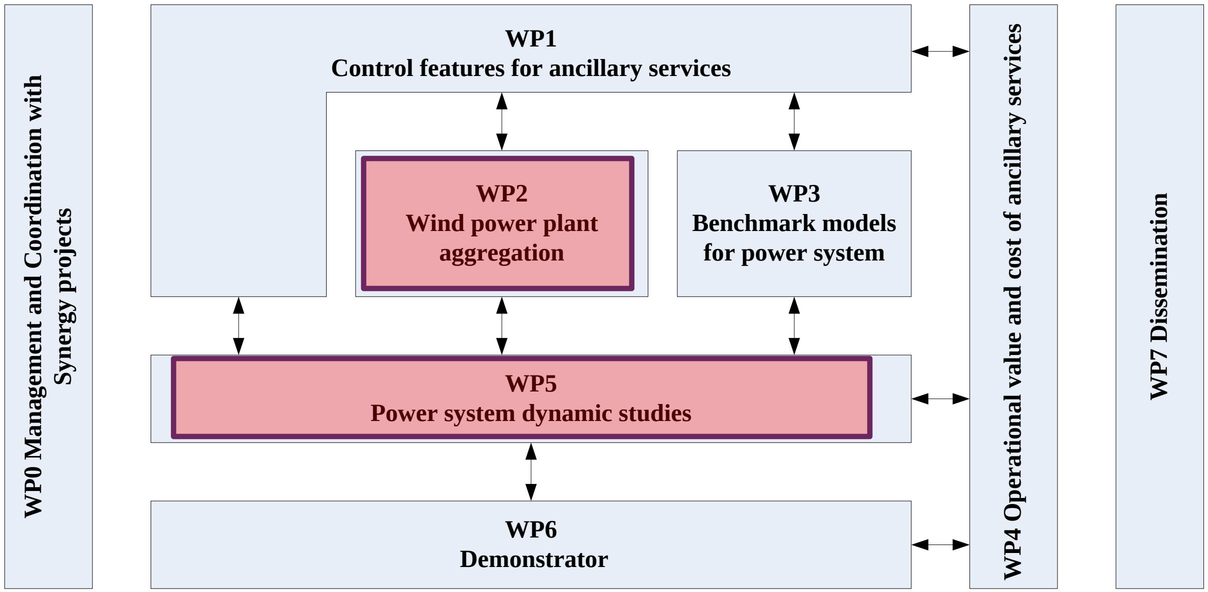
Wind Power Plants and Grid Integration



Enhanced Ancillary Services from Wind Power Plants (*EASEWIND*)

To develop, asses and demonstrate technical solutions for enabling wind power to have similar power plant characteristics as conventional generation units.





IEC 61400-27
Electrical simulation models for wind power generation

- IEC TC88 WG27:
  - Scope
    - Develop generic models for wind power generation
    - Procedures for validation of models
  - Work with new standard initiated in 2009
  - Two parts
    - 1. Wind turbines (standard by 2012)
    - 2. Wind farms (standard by 2014)
  - 32 members from 14 countries, industry (TSOs, power producers, consultants) and research
  - Risø DTU convener (project manager)

- Danish support project
  - DTU (Risø and Elektro), Energinet.dk, Vestas, SIEMENS, Suzlon, Gamesa, DONG Energy, Vattenfall

Grid Compliance Test Facility

- Facility currently in planning phase
- National Test Centre for Wind Turbines
- Test stands for 7 large turbines
- Turbines up to 20MW / 250m
- Advanced grid connection test equipment

- Collaboration between:
  Risø DTU
  Wind Turbine Industry Association
  Turbine manufacturers
  Developers & owners

SDC PhD in
Wind Power Plants System Services

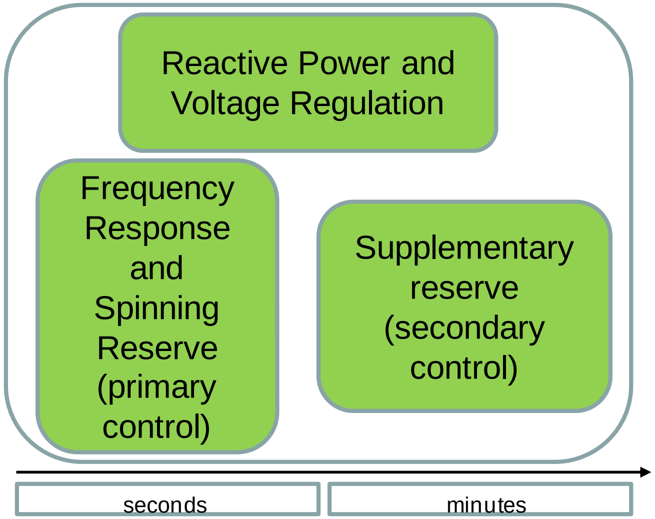
Ph.D project financially supported by
Sino-Danish Center for Education and research (SDC)

Overall goal:

- to analyze and assess the possibilities to exploit wind power plants capabilities to support the power system in a similar way as a conventional power plant does.

Focus on:

- integration of large wind power into the power system
- development and modelling of different technically viable solutions, which increase the ability of wind farms to provide system services
- study the impact on the power system of large and concentrated penetration of wind farms with controllers delivering ancillary services
- case studies – Denmark and China



Collaboration:

- CEPRI
- IEE CAS

Status:

- 57 applicants
- Candidate found / enrolment on-going
- Expected start date:15 dec. 2011


Thank you