



# Strategic Research Agenda Market Deployment Strategy

From 2008 to 2030

Annex A:

Detailed research actions

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## Introduction

The TPWind Strategic Research Agenda is divided into five thematic priorities for research, in order to support the implementation of the 2030 vision. These thematic priorities are:

- wind resources, design wind conditions, and forecasting;
- wind turbine technology;
- wind energy integration;
- offshore deployment and operation; and
- European research infrastructures.

For each thematic priority, a 2030 objective is given. The aim is to meet each objective by carrying out the relevant research, and each thematic priority is therefore allocated various research topics. For each topic, short-, medium- and long-term research priorities are defined, and research actions are then established to meet these priorities. This approach is illustrated in the diagram opposite.

The Strategic Research Agenda document provides the research priorities for each research topic.

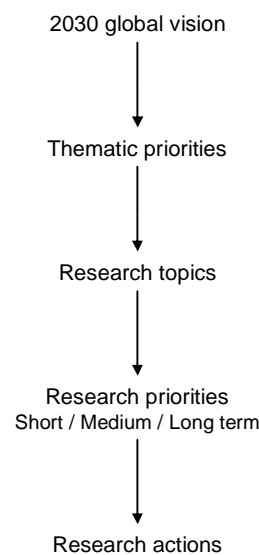


Figure 1: Illustration of SRA analysis. Thematic priorities are supported by research topics, which are divided into research priorities and research actions.

For each of these priorities, the following sections provide the detailed research actions for the short-, medium- and long-term. This constitutes a detailed action plan for wind energy research over different time periods.

## A Wind conditions

### A.1 Siting in complex or forested terrain

#### A.1.1 Short term

Askervein II	Detailed measurement campaigns providing high-quality measurements of wind speed, direction and turbulence at several heights and positions from a number of representatively complex and forested sites. Instruments will include 50 masts, Lidars, Sodars, ceilometers, scintillometers (etc.) in order to monitor the spatial and temporal evolution of the wind field at a high spatial and temporal resolution. This will start from 30m above ground level. In the best case, the selected sites will serve as locations of future wind parks, in order to obtain long-term data series from the developers.
Advanced models	Evaluation of methodologies for CFD model use, adapted to the long-term simulations for wind resource estimation. These methods are based on coupling with meso-scale model and data assimilation. Development of a 'best practice' guide.
New measurement techniques	<ul style="list-style-type: none"> <li>• Mapping of horizontal wind fields over complex terrain by ground-based remote sensing (3D)</li> <li>• Remote sensing of mean wind profiles over complex terrain, comparison with reference measurements in difficult conditions (strong winds, very cold climates, very dry climates, rain, snow..)</li> <li>• Validation of turbulence measurements by remote sensors</li> <li>• Improvement of remote sensing services and adaptation in anticipation of the needs of the wind industry</li> <li>• Demonstration of the potential, the limits and the qualities of satellite-based data sets</li> </ul>

#### A.1.2 Medium term

Standards for wind resource assessment	<p>Initiation of an R&amp;D project involving manufacturers, promoters and R&amp;D institutions, in order to reach a consensus on methodology. The objectives are:</p> <ul style="list-style-type: none"> <li>• to identify critical steps in the wind resource assessment process</li> <li>• to identify the accuracy and the quality of the input data sets needed for the various solutions and approaches. To identify the potential of remote sensing for feeding the models;</li> </ul>
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	<ul style="list-style-type: none"> <li>• to compare present solutions or approaches through experiments;</li> <li>• to minimise risk;</li> <li>• to agree on a robust method or procedure that will form the basis for a standard method;</li> <li>• to develop a fully-integrated method based on satellite data and modelling for wind resource assessment;</li> <li>• to define what will be needed for future observation work – this can then be included in the development of new satellite sensors</li> </ul>
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### A.1.3 Long term

Advanced models: development and calibration of turbulence models	<ul style="list-style-type: none"> <li>• Employ the most up-to-date and advanced knowledge of the effects of natural terrain on the atmospheric boundary layer</li> <li>• Include stratification and stability issues</li> <li>• Intelligent coupling with the fastest and most widely-used wind resource prediction codes</li> <li>• Coefficient sets in the very popular ‘k-e’ and ‘k-w’ models have been obtained from theoretical considerations and one single wind tunnel experiment, but have not yet been tested in real atmospheric conditions. A dedicated experiment would allow for a proper calibration of the turbulence constants for atmospheric flows.</li> </ul>
Advanced models: a unified model	The development of a model (or model suite) which spans all time and length scales, from a global scale to less than 50m for load calculations in highly-complex terrain with steep slopes and forest clearings. The model is to be used for resource and load calculations in wind atlas mapping.

## A.2 Offshore Wind Power Meteorology

### A.2.1 Short term

Design conditions for offshore sites	Development of a standardised method for describing combined wind and wave statistics.
Dedicated offshore short-term forecasting models	Development of dedicated offshore wind power forecasting, including specific offshore meteorology, online measurements and satellite remote sensing data.
Fully integrated wind-wave-current	Carry out comprehensive research measurements of the marine atmosphere, waves and currents in close cooperation with the

interaction models	meteorology and oceanography research communities.
Basic knowledge about the marine atmosphere	<ul style="list-style-type: none"> <li>• Experiments that investigate the land/sea discontinuity of flow over the sea</li> <li>• Development of a micrometeorological model for a height profile of wind over the sea, including the influence of boundary layer height, internal boundary layers, low-level jets, atmospheric stability, wind/wave/current interaction and so on</li> <li>• Close cooperation with the meteorology and oceanography research communities is required</li> </ul>
Improvement of meteorological models for offshore conditions	<ul style="list-style-type: none"> <li>• Improved surface layer parameterisations of NWP and other meteorological models for flow over the sea</li> <li>• Close cooperation with the meteorology and oceanography research communities is required</li> </ul>
Ground-based (and floating) remote-sensing techniques	Improved availability of data and accuracy for ground-based offshore remote sensing
Satellite-based remote sensing for the offshore wind industry	<ul style="list-style-type: none"> <li>• Demonstration of the potential, the limits and the advantages of satellite-based data sets</li> <li>• Comparison and validation of satellite-based offshore wind in front of a grid of buoys</li> <li>• Development of an operational method for offshore wind mapping based on satellite data</li> </ul>

## A.2.2 Medium term

Standard models for resource assessment	Establishment of standard models and methods for offshore locations.
Dedicated offshore short-term forecasting models	Development of models with an extended forecast horizon for offshore maintenance planning.
Fully integrated wind/wave/current interaction models	Development of a fully-integrated wind/wave/current interaction model as the basic model for wind resource studies.
Basic knowledge about the marine atmosphere	Investigations into the presence and the importance of coherent turbulence structures over the sea.
Ground-based (and floating) remote	Development of a standard method for stand-alone long-term monitoring of the wind resource from offshore platforms.

sensing techniques	
Satellite-based remote sensing for the offshore wind industry	<ul style="list-style-type: none"> <li>• Development of a fully-integrated method based on satellite data and modelling for wind resource assessment</li> <li>• Definition of satellite observations that will be useful for wind energy in the future</li> </ul>

### A.2.3 Long term

Standard models for resource assessment	Development of a standard resource assessment method based on satellite remote sensing data and combined with a flow model with fully coupled wind/wave/current interactions.
Ground-based (and floating) remote sensing techniques	Development of a remote sensing technique using a floating structure for offshore resource assessment measurements.
Satellite-based remote sensing for the offshore wind industry	Use of high-resolution Lidar measurements from satellites for wind profiles.

## A.3 Wakes

### A.3.1 Short term

Data analysis	Increase the number of available data sets from large wind farms through measurement campaigns in offshore and complex terrains.
Advanced models	<ul style="list-style-type: none"> <li>• Improve model capabilities</li> <li>• Combine atmospheric and aeroelastic CFD models</li> <li>• Evaluate the use of CFD, particularly in complex terrain</li> </ul>

### A.3.2 Medium term

Data analysis	Measurements of mean wind and turbulence as 3D structures over the entire rotor plane (cf. wind scanner). 3D measurements of wind and turbulence in the wakes.
Advanced models	<ul style="list-style-type: none"> <li>• Wind farm models for the optimisation of wind farm layouts</li> <li>• Stability impact on wakes, particularly offshore</li> </ul>

### A.3.3 Long term

Advanced models	<ul style="list-style-type: none"> <li>• The inclusion of a combination of power loss and loads from wakes in models in order to evaluate layout more comprehensively</li> <li>• Consider how wake losses may be reduced other than by changing spacing</li> <li>• High-resolution wind field models for wakes</li> </ul>
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## A.4 Extreme Wind Speeds

### A.4.1 Short term

Data analysis	<ul style="list-style-type: none"> <li>• Investigate the different re-analysis data with respect to extreme wind analysis, comparison and validation against the European Wind Atlas, incorporate data and stations across Europe as a validation study</li> <li>• Analyse high-frequency wind data and develop methods for the characterisation and classification of high-frequency extreme wind speed changes</li> <li>• Develop methods for downscaling the reanalysis data (using meso-scale and linearised model)</li> <li>• Develop a method for calculating extreme winds, including directional information</li> </ul>
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### A.4.2 Medium term

Advanced models	<ul style="list-style-type: none"> <li>• Improve downscaling models (include more terms in linearised flow models and include CFD models)</li> <li>• Investigate the relation between <math>v_{ref}</math> and the three-second gust, including the vertical and horizontal structure of gusts</li> <li>• Establish a classification scheme for high-frequency extreme wind changes</li> <li>• Investigate the uncertainties regarding <math>v_{ref}</math>, by reviewing the ways in which it is estimated, including other sources of extreme events (e.g. thunder clouds) and the influence of atmospheric stability</li> <li>• Investigate the structure of the extremes in order to find generic rules that can be applied to them.</li> </ul>
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### A.4.3 Long term

Produce a globally-integrated 'Extreme and Resources Climate Atlas' which includes the effects of cyclones and other extreme events

## A.5 Wind profiles at great heights and advanced measurement techniques

### A.5.1 Short term

Data analysis	Measurements of wind and turbulence profiles at 250m and above combined with measurements of boundary layer height
New measurement techniques	<ul style="list-style-type: none"> <li>• Definition of methodologies for remote sensor use which are adapted to wind energy applications: compromise between time series duration and measurements on several points of the site, use of shear information (definition of an equivalent wind speed)</li> <li>• Inclusion of remote sensors in standards for resource assessment as well as power curve estimation</li> </ul>

### A.5.2 Medium term

Advanced models	<ul style="list-style-type: none"> <li>• Implement LES modelling of the wind profile, including the effect of the temperature profile above the boundary layer</li> <li>• Propose methods of ascertaining the boundary layer height in NWP and meso-scale RANS models</li> </ul>
New measurement techniques	<ul style="list-style-type: none"> <li>• Propose and test instruments and methods for the operational determination of the height of the boundary layer; back-scattering Lidar, ceilometer or other remote sensing instruments</li> <li>• Develop ground-based remote sensing for wind resource assessment, wind turbine control and performance optimisation, and turbulence and wake modelling</li> </ul>

### A.5.3 Long term

Advanced models	<ul style="list-style-type: none"> <li>• Investigate the wind profile and boundary layer height structure over complex terrain</li> <li>• 4D modelling of design parameters and turbulence for the full atmospheric boundary layer</li> </ul>
New measurement	Use of high-resolution Lidar measurements from satellites for wind

techniques	profiles
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## A.6 Short-term prediction

### A.6.1 Short term

Data analysis and new measurement techniques	<ul style="list-style-type: none"> <li>• Use of real-time or near real-time measurement data (e.g. wind farm power measurements, mast measurements, Lidar or satellite measurements) for very short-term forecasting, system integration and safe grid operation</li> <li>• Integration of online wind measurements from masts, remote sensing (offshore) and the turbines themselves to improve accuracy</li> </ul>
Advanced models	<ul style="list-style-type: none"> <li>• Improve accuracy regarding average and extreme errors through: <ul style="list-style-type: none"> <li>○ better understanding of error modes;</li> <li>○ improved meteorological models, using multiple models and weather-dependent selection of models;</li> <li>○ dedicated models for extreme events;</li> <li>○ coupling of wind and wave models for offshore; and</li> <li>○ determining the intrinsic noise levels of forecasting scenarios through a stochastic approach.</li> </ul> </li> <li>• Investigate prediction uncertainty, especially in the field of multi-model combined forecasting<sup>1</sup>: <ul style="list-style-type: none"> <li>○ Characterise forecast uncertainty by understanding the impact of weather regimes on it. Multi-model combined (or regime-switching) forecasting approaches should minimise prediction errors, depending on the weather regime, thus lowering the overall forecast uncertainty</li> <li>○ Model the interdependence of prediction errors at various locations, and at various points in time</li> </ul> </li> </ul>

### A.6.2 Medium term

Advanced models	<p>Integrate prediction into the day-to-day management of the power system, through:</p> <ul style="list-style-type: none"> <li>• dedicated weather models for wind power;</li> <li>• investigation into coupling between meteorological forecast and wind power conversion systems;</li> </ul>
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<sup>1</sup> Please note that works carried out towards a better understanding and modelling forecast uncertainty will also impact forecast accuracy in the medium to long term

	<ul style="list-style-type: none"> <li>• inclusion of variability of forecasts;</li> <li>• interoperability of forecast tools, e.g. development of a data communication standard in IEC.</li> </ul>
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### A.6.3 Long term

Advanced models	Integration of wind power forecast into numerical weather forecast models and wind power measurements in data acquisition.
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## B Wind power systems

### B.1 Wind turbine as a flow device

#### B.1.1 Short term

Advanced models	<ul style="list-style-type: none"> <li>Continued development of 'hybrid' CFD–BEM methods for designing new rotor blades. These methods should use new aerodynamic flow devices. CFD research should include modelling of neighbouring wind turbines and terrain effects</li> <li>Incorporate boundary layer theory into CFD</li> </ul>
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#### B.1.2 Medium term

Model validation	Extensive experimental verification of design models and prototype models of devices and complete blades.
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### B.2 Wind turbine as mechanical structure/materials

#### B.2.1 Short term

Loads	<ul style="list-style-type: none"> <li>Develop and verify wind turbine safety design methodology (e.g. design safety level, safety factors, partial coefficient design methods). Safety factors are used as a way to take uncertainty into account in the design. Smart control systems can reduce uncertainty and so can be used to decrease the safety factors</li> <li>Apply the most recent knowledge on finite elements calculations to structures</li> </ul>
Materials	<ul style="list-style-type: none"> <li>Continue research into new materials (SN curves, Palmer Miner rule) in order to keep catalogue of material properties updated</li> <li>Develop more realistic physical models and experimental research for materials, from nano-scale to full-scale models and tests</li> </ul>
System Reliability	<ul style="list-style-type: none"> <li>Standardise components</li> <li>Research on lubrication, bearings and gearboxes is necessary</li> <li>Reliable and cost-effective sensors are needed for condition monitoring</li> </ul>
Drive trains	<ul style="list-style-type: none"> <li>Further develop dedicated reliability methods for wind</li> </ul>

	<p>turbines, particularly for offshore machines</p> <ul style="list-style-type: none"> <li>• Improve performance of bearings and gearboxes on the basis of reliability analysis and dynamic modelling of the entire drive train and loads induced by the rotor and electric generator. Concepts for limiting torques in transmission system could increase gearbox reliability</li> </ul>
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## B.2.2 Medium term

Loads	Develop materials (piezo electric materials, memory steel alloys) for activating aerodynamic devices in advanced rotors.
Materials	<ul style="list-style-type: none"> <li>• Develop alternatives to steel towers</li> <li>• Develop construction materials which can be fully recycled while possessing the required mechanical properties. Thermoplastics are likely to offer this possibility as they can be recycled and used for new structural designs (e.g. rib and spar constructions) for wind turbine blades, which incorporate aerodynamic control devices</li> </ul>
Drive trains	Apply fundamental mechanics to drive train analysis (UpWind).

## B.3 Wind turbine as an electricity plant

### B.3.1 Medium term

Grid connection	<ul style="list-style-type: none"> <li>• Improve knowledge of the interaction of the wind turbine electric system with the grid. Parameters used in the design process need to be better identified and monitored</li> <li>• Power electronic loads, grid faults and wind turbine fault can lead to critical situations not taken into account when the grid was designed. Design standards including loads from power, electronic, grid faults and wind turbine faults need to be developed</li> <li>• The electric and mechanical properties of full-size novel electric conversion systems need to be tested before being applied on a large scale (e.g. at offshore locations). Also commissioning procedures have to be established in connection with full-size testing</li> </ul>
Power electronics	Develop power electronics that work at high(er) voltage levels in order to increase efficiency and to reduce costs.
Power converters	Improve power converters in terms of partial load efficiency as a function of rotor loading in order to maximise annual electricity output and capacity factor.

### B.3.2 Long term

New generators	Design, develop and test novel generator types, possibly incorporating super conducting wiring. The goal is to build compact, light-weight, low speed, maintenance free and controllable generators.
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## B.4 Wind turbine as a control system

### B.4.1 Short term

Control and condition monitoring	<ul style="list-style-type: none"><li>Analyse causes of outages for various external circumstances (notably offshore) and define relevant action to resolve problems</li><li>Develop relevant sensors for control and condition monitoring</li></ul>
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### B.4.2 Medium term

Rotor control strategies	Develop dedicated rotor control strategies, notably for distributed rotor blade control that incorporates aerodynamic devices.
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### B.4.3 Long term

Integral adaptative strategies	Develop integral adaptive control strategies for varying external conditions both for wind farms and wind turbines. Wind farm control might require the use of data on the behaviour of other wind turbines inside the wind farms.
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## B.5 Innovative concepts and integrated design

### B.5.1 Short to medium term

Integral design	<ul style="list-style-type: none"><li>Develop integral design tools for global system optimisation</li><li>Include integral design tools in standard design and certification processes</li><li>Develop an integral design base, and keep it updated</li><li>Develop fully integrated concepts including support structures/foundations and transport</li></ul>
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### B.5.2 Medium to long term

Advanced rotor	<ul style="list-style-type: none"><li>Design aerodynamic control devices especially for very large</li></ul>
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concepts	<p>rotor blades and testing</p> <ul style="list-style-type: none"> <li>• Come up with new rotor concepts for offshore; rotors with higher tip speed ratios than used on land</li> </ul>
Innovative concepts	<ul style="list-style-type: none"> <li>• Explore two-bladed wind turbines and new concepts. Further investigations regarding: <ul style="list-style-type: none"> <li>○ Two-bladed rotor concepts for offshore: higher tip speed ratios, no acoustic emission limitations, lighter rotors and conversion systems</li> <li>○ Downwind rotors for more compact nacelles and which avoid heavy yawing systems</li> </ul> </li> <li>• New concepts for offshore wind turbines at large distances from shore (&gt;100 km), (e.g. larger size, improved reliability and so on)</li> </ul>

## B.6 Operation and maintenance

### B.6.1 Short term

Maintenance strategies	Develop methods for preventive, risk-based inspection using condition monitoring.
Failure identification	<ul style="list-style-type: none"> <li>• Investigate the physical effects of faults in wind turbine components and their development (100% research)</li> <li>• Integration of condition monitoring and fault prediction capabilities into the wind turbine's control system to achieve synergy effects, (e.g. with double-used sensors)</li> </ul>

### B.6.2 Medium term

Maintenance strategies	Develop condition-based and predictive maintenance strategies
Failure identification	Investigation into the effects of redundant components (e.g. doubling the oil filter system) on offshore wind turbine reliability (80% research and 20% demonstration).

### B.6.3 Short to long term

Failure identification	Get long-term experience with condition monitoring, wind farm control, grid behaviour, fault statistics, etc. (80% demonstration and 20% research).
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## C Wind energy integration

### C.1 Wind power plant capabilities

#### C.1.1 Short / medium term

Grid code requirements	<p>Integration requirements for all power producers as a function of wind power penetration onshore and offshore:</p> <ul style="list-style-type: none"> <li>• Voltage control</li> <li>• Improved IT services to TSO (real time data, control functions, forecasting)</li> <li>• Reactive power support (different connection points)</li> </ul>
Means of verification	Determine means of verifying (measurement/simulation) specific capabilities (e.g. FRT) and methods of proving compliance

#### C.1.2 Medium / long term

Opportunities for meeting requirements	Opportunities for meeting requirements as a function of wind power penetration (e.g. power electronics, control strategies, monitoring, automation).
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### C.2 Grid planning and operation

#### C.2.1 Short term

Accelerated and sustainable extension and reinforcement, transmission adequacy	<ul style="list-style-type: none"> <li>• Strategy for increasing acceptance concerning the ongoing and future grid extension measures needed for wind power</li> <li>• EU-wide mapping of the various existing national and federal legal frameworks concerning grid extension permission procedures, in preparation of an effective European regulation which will enable the transportation of large-scale wind power</li> </ul>
Improved operation, interoperability	<ul style="list-style-type: none"> <li>• Develop operational tools and techniques for data acquisition (online and operational data, wind characteristics)</li> <li>• Real time determination of network transmission capacity (NTC)</li> <li>• Develop and test new equipment, (e.g. superconducting fault current limiter)</li> <li>• Improve wide area monitoring and control (WAM&amp;C) and wide area protection (WAP)</li> <li>• Wind power prediction tools for (local) grid operation</li> </ul>

Models/simulation tools	Requirements, models and generic WT/WF models are being validated and implemented in an on-going process
Transmission studies for offshore wind power	HVAC, HVDC, LCC versus VSC

## C.2.2 Medium term

Accelerated and sustainable extension and reinforcement, transmission adequacy	<ul style="list-style-type: none"> <li>• Improve transmission technologies (e.g. FACTS, high voltage cable technologies, increasing voltage, line monitoring)</li> <li>• Transmission adequacy: <ul style="list-style-type: none"> <li>○ Europe-wide planning, interconnections;</li> <li>○ maintain security and reliability;</li> <li>○ take expected Europe-wide wind power development and long-term forecasting of transmission bottlenecks into account.</li> </ul> </li> </ul>
Improved operation, interoperability	<ul style="list-style-type: none"> <li>• Europe-wide operation, TSO collaboration in a coordinated way, Europe-wide physical distribution of wind energy in order to enable high wind power infeed while maintaining the system stability of the individual control areas</li> <li>• WAM&amp;C and WAP at European level</li> <li>• Europe-wide Dynamic Security Assessment (DSA)</li> <li>• Wind power management as integral part of grid operation</li> </ul>
Models/simulation tools	<ul style="list-style-type: none"> <li>• Tools for dynamic calculations of the interconnected European power system</li> <li>• Generic wind turbine / wind farm models</li> </ul>
Transmission studies for offshore wind power	<ul style="list-style-type: none"> <li>• Multi-terminal HVDC, mixed HVAC/HVDC grids</li> <li>• Offshore grid topologies</li> <li>• Combined offshore wind and trade grids</li> <li>• Wind farm power collection system including substation, especially for large wind farms (&gt;1,000 MW)</li> </ul>
New power system architecture	<ul style="list-style-type: none"> <li>• Development and testing of new power system architecture, (e.g. cell concept or agent-based systems with self-healing properties)</li> </ul>

### C.2.3 Long term

Transmission studies for offshore wind power	<ul style="list-style-type: none"> <li>• Meshed HVDC offshore grids</li> <li>• Offshore grid topologies</li> <li>• Combined offshore wind and trade grids</li> <li>• Wind farm power collection system including substation, specifically for large wind farms (&gt; 1,000 MW)</li> </ul>
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## C.3 Energy and power management

### C.3.1 Short term

System operation	<ul style="list-style-type: none"> <li>• Improved system and portfolio management tools for TSOs and market parties, regional and system-wide, including:             <ul style="list-style-type: none"> <li>○ integration of frequently updated wind power forecasts, uncertainties and risk estimates into the system;</li> <li>○ real-time data, two-way communication between wind farms and TSOs;</li> <li>○ decision tools with probabilistic methods;</li> <li>○ support of interaction between wind, other RES, storage and demand-side management;</li> <li>○ (distributed) dispatch;</li> <li>○ adapted to the competitive market.</li> </ul> </li> <li>• Assessment and demonstration of benefits and costs of several options for ancillary services and power balancing in higher wind penetrations - <b>phase 1</b>:             <ul style="list-style-type: none"> <li>○ focus on wind power plant capabilities (curtailing wind power production).</li> </ul> </li> </ul>
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### C.3.2 Medium term

System operation	<p>Assessment and demonstration of benefits and costs of several options for ancillary services and power balancing in higher wind penetrations - <b>phase 2</b>:</p> <ul style="list-style-type: none"> <li>• Europe-wide balancing with smoothing of wind variability and forecast errors</li> <li>• Direct power exchange between areas with not enough and surplus wind power by an European overlay transmission grid</li> <li>• Demand-side management</li> <li>• Virtual power plants using back-up generators or heat/cooling</li> </ul>
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	storage for system balancing <ul style="list-style-type: none"> <li>• Flexible operation of existing generation (CHP)</li> </ul>
Long-term planning	<ul style="list-style-type: none"> <li>• Impacts of a high penetration of wind on power system operations:             <ul style="list-style-type: none"> <li>○ simulations of future power systems 2020/2030 models/tools;</li> <li>○ small and large systems at European level;</li> <li>○ incorporating wind power variability and forecast errors on different time scales to long-term planning tools;</li> <li>○ solutions for balancing and future options.</li> </ul> </li> <li>• Investigate high penetration of wind power in isolated grids</li> <li>• Evaluate impacts of high penetration of wind on power adequacy</li> <li>• Long-term (seasonal) wind energy forecasts for portfolio planning</li> </ul>

### C.3.3 Long term

System operation	Assessment and demonstration of benefits and costs of several options for ancillary services and power balancing in higher wind penetrations - <b>phase 3</b> : <ul style="list-style-type: none"> <li>• Storage (e.g. hydro power reservoirs/pumped, heat, compressed air, liquid fuels)</li> <li>• Future options (electric vehicles, hydrogen)</li> </ul>
Long-term planning	100% renewables system: interaction of wind/solar/wave/hydro/biomass, electricity and fuels.

### C.4 Demonstration actions

Specific demonstration actions are proposed. These actions are listed in Table 1.

One of the main points raised during discussions was the need for education, and the sharing of wind integration experience with TSOs and utilities. The creation of the equivalent of the US network *Utility Wind Integration Group*<sup>2</sup> is recommended.

<sup>2</sup> The Utility Wind Integration Group (UWIG), previously the Utility Wind Interest Group, was established in 1989 to provide a forum for the critical analysis of wind technology for utility applications and to serve as a source of credible information on the status of wind technology and deployment. The mission is to accelerate the development and application of good engineering and operational practices supporting the appropriate integration of wind power into the electric system. The regular working group meetings and seminars have proved an effective way of sharing their experience in wind integration and finding ways to estimate the impacts of such integration: [www.uwig.org](http://www.uwig.org)

Main area	Research priority	Demonstration action
Wind power plant capabilities	Grid code requirements	<ul style="list-style-type: none"> <li>• Influence of requirements upon wind turbines electrically and mechanically</li> <li>• Detailed simulation and field measurements to find out what happens at WT/WF connection points during symmetrical and unsymmetrical grid faults</li> </ul>
Wind power plant capabilities	Opportunities for meeting requirements	Demonstrate the concept of wind power plant pilots
Wind power plant capabilities	Determine means of verification	Monitoring of voltage dips
Grid planning and operation	Proof of concept	Multi-terminal HVDC connections (offshore)
Energy and power management	System operation	<ul style="list-style-type: none"> <li>• Improved system and portfolio management tools</li> <li>• Demand-side management combined with wind power</li> </ul>
Energy and power management	Long-term planning	Investigate high penetration of wind power in isolated grids.
Electricity market	Market access	Test demand elasticity in markets.

Table 1: Demonstration actions supporting thematic priority on wind energy integration

## D Offshore deployment and operations

### D.1 Market deployment and research actions

#### D.1.1 Market deployment actions

The key market deployment actions lie in the development of infrastructure that allows Europe to reach its ambitious goals for offshore wind. The infrastructure – vessels, factories, harbours etc. – must be built, and technological improvements to increase the rate of manufacturing and installation are needed. Political will is needed in order to balance environmental protection with development challenges and to establish an effective grid system to deliver the power to market.

<b>Safety</b>	
Short term	<ul style="list-style-type: none"> <li>• Safe and effective access to offshore structures for people and equipment</li> <li>• Development of a set of common standards for HSE policies in the offshore wind industry, consistent with national HSE regimes and applicable across Europe</li> </ul>
Long term	Training and education in wind energy / offshore wind energy.
<b>Education</b>	
Short term	Train the workforce to manufacture, install, operate and maintain the hardware
Long term	Develop programmes to deliver trained, skilled developers, engineers and policy-makers
<b>Environment</b>	
Short term	<ul style="list-style-type: none"> <li>• Share data on the natural environment</li> <li>• Clarify and standardise Environmental Impact Assessment criteria and harmonise the process across Europe</li> </ul>
<b>Substructures</b>	
Short term	<ul style="list-style-type: none"> <li>• Improve manufacturing facilities and set up new ones so that a variety of substructure designs can be built in large numbers at lower costs and with high-quality standards</li> <li>• New and improved manufacturing processes and procedures, which apply the latest technologies in automation, robotics etc. in order to reduce costs, increase volume and deliver quality and price</li> <li>• New and improved manufacturing technologies such as welding/casting, cutting, concreting, corrosion protection etc. to reduce costs, increase volume and deliver quality and price</li> </ul>

Long term	Develop a competitive supply chain.
<b>Installation assembly and decommissioning</b>	
Short term	<ul style="list-style-type: none"> <li>• Construct and deploy sufficient vessels and equipment to meet the demands of the installation programmes. They should be capable of coping with the range of turbines, substructures and environmental conditions that will be encountered</li> <li>• Develop safe, efficient, reliable and repeatable processes to reduce costs, minimise risks, guarantee standards and deliver investor confidence</li> <li>• Develop onshore facilities which provide efficient transport links, large lay down areas and good harbours</li> </ul>
<b>Electrical Infrastructure</b>	
Short term	<ul style="list-style-type: none"> <li>• Develop better infield cabling design, cabling technologies and installation processes to deliver cost reductions and reliability</li> <li>• Invest in cable manufacturing facilities and cable installation vessels and equipment</li> </ul>
Long term	Develop a grid system which allows the full potential of offshore wind to be exploited through interconnected offshore cable systems and improved regulatory regimes.
<b>Turbines</b>	
Short term	<ul style="list-style-type: none"> <li>• Invest in new equipment to manufacture the components and assemble the turbines</li> <li>• Improve the reliability of the equipment through better design, component quality, marinisation and operating experience, and by sharing that experience effectively</li> <li>• Development of onshore and offshore test facilities to ensure that the turbines are properly tested before commercial offshore deployment</li> </ul>
Long term	Develop a competitive supply chain.
<b>Operation and maintenance</b>	
Short term	<ul style="list-style-type: none"> <li>• Access systems should allow the safe and efficient transfer of people and equipment to offshore installations</li> <li>• Vessels and equipment for the repair and maintenance of the machines. They should be able to lift the heaviest components into and out of the nacelle</li> <li>• Access to offshore structures</li> <li>• Develop maintenance strategies which maximise production and minimise costs</li> </ul>

Long term	<ul style="list-style-type: none"> <li>• Reduce the amount of maintenance the machines need by designing components which can be replaced with a minimum of dismantling, using as little external lifting equipment as possible. Install lifting points, cranes, hoists and winches to simplify operations</li> <li>• Better management systems for the monitoring and checking of turbines. The systems should assist with the scheduling and implementation of offshore activities</li> <li>• Develop a competitive supply chain</li> </ul>
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### D.1.2 Research actions

The research actions are aimed at developing new concepts to extend the operating environment of the equipment, to increase its reliability and operability.

<b>Safety</b>	
Long term	Development of safety concepts for remote wind farms.
<b>Environment</b>	
Long term	<ul style="list-style-type: none"> <li>• Better understanding of climate (meteorological/oceanic) to improve resource quantification and assessment of the physical environment offshore</li> <li>• Better geotechnical data and improved techniques for assessing soil parameters and their variation across development sites</li> </ul>
<b>Substructures</b>	
Short term	<ul style="list-style-type: none"> <li>• Develop new substructure concepts</li> <li>• Acquire data on the performance of existing structures to support the development of improved design tools and better standards</li> </ul>
Long term	<ul style="list-style-type: none"> <li>• Develop improved designs to extend the life of structures, to reduce costs and to incorporate risk-based life cycle approaches for future designs</li> <li>• Develop, engineer and demonstrate floating designs for deep water developments</li> </ul>
<b>Assembly, installation and decommissioning</b>	
Short term	Optimisation of existing assembly and installation methods
Long term	<ul style="list-style-type: none"> <li>• Develop new installation concepts and extend them to more hostile waters</li> <li>• Integrate installation concerns at early stages of design of turbine and substructure</li> <li>• Life-cycle approaches including installation and decommissioning</li> </ul>
<b>Electrical Infrastructure</b>	
Long term	<ul style="list-style-type: none"> <li>• Develop improved design tools</li> <li>• Develop life-cycle approaches to reduce costs, increase reliability and extend the lifetime of the facilities</li> </ul>

<b>Turbines</b>	
Short term	Improve understanding of wake effects to allow the optimisation of array layout, minimisation of energy loss and reduction of wear and tear on the machines
Long term	<ul style="list-style-type: none"> <li>• Develop turbines specifically for the offshore market</li> <li>• Improved turbine design and simulation techniques to deliver larger turbines and improved reliability</li> </ul>
<b>Operation and maintenance</b>	
Short term	Development of condition- and risk-based maintenance systems, designed to improve operational efficiency and reduce costs
Long term	<ul style="list-style-type: none"> <li>• Reduce human intervention by designing turbines with remote functionality and redundancy</li> <li>• Life-cycle approach to turbine design which balances increased capital cost of reliability with higher operating costs over turbine life</li> </ul>