



Strategic Research Agenda Market Deployment Strategy

From 2008 to 2030

Annex B:

State-of-the-art and current insufficiencies

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Introduction

The TPWind Strategic Research Agenda (SRA) is divided into five thematic priorities for research, in order to support the implementation of the 2030 vision. For each thematic priority, a 2030 objective is given. The aim is to meet each objective by carrying out 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. The Strategic Research Agenda document provides the research priorities for each research topic. Annex A provide the detailed research actions at short-, medium- and long-term.

The same process was performed for defining the Market Deployment Strategy (MDS) priorities.

Both analyses were based on TPWind 2030's vision for the future and the current knowledge. The following sections provide the background analysis of the state-of-the-art and current insufficiencies for all sections of the SRA and MDS documents.

A Wind conditions

A.1 Siting in complex or forested terrain

Current issues regarding siting in complex orography and forested areas

The determination of local wind resources and loads in complex terrain is of major importance¹. Wind turbines may be exposed to loads exceeding the design loads basis and eventually break down. Even with state-of-the-art linear methods for wind resource prediction, wind shear, wind veer and turbulence may very well exceed the determined values due to the local orography.

At this stage, advanced flow modelling for wind loads and resources has still not been verified and validated at a satisfactory level. It is therefore of major interest to improve and develop models for complex sites in order to characterise the turbulence and flow at any given position and height.

An increasing number of wind farms are being proposed in, or adjacent to, forested areas (native forestry as well as commercial plantations), throughout Europe and elsewhere. In Europe in particular, forested areas often coincide with complex terrain. This raises a number of potentially significant technical and commercial issues, such as:

- Decreased wind speeds/energy yields for the wind farm project
- Forested areas are places of increased turbulence and vertical shear, and can lead to potential turbine vibration and subsequent component fatigue
- Due to the complex flow environment, estimates of annual energy production may be subject at best to high uncertainty or at worst to inaccuracy, increasing the risk that the project does not perform well financially

¹ R.G. Derickson et al (2004): *Resolving Difficult Issues of Wind Power Micrositing in Complex Terrain*

- Environmental pressures may lead to absolute minimum felling of forestry areas
- The full impacts of siting in forests are poorly understood, so developers often take a precautionary approach
- Developers often find that turbine manufacturers have reservations about warranties because of uncertainty regarding wind quality, and this affects the competitiveness of the turbine procurement process

In order to solve these issues, we need a deep understanding of complex and forested areas, as well as new modelling methods and highly-resolved measurements from remote sensing techniques. To this end, we have to develop advanced non-linear methods for flow prediction, based on CFD methodology.

Using advanced models: computational fluid dynamics modelling (CFD)

The local wind at one position is not directly dependent on local wind conditions at a second position, due to the highly non-linear flow in complex terrain. The use of linear methods may therefore lead to flawed predictions of the wind conditions at the prospective positions of wind turbines in a planned wind farm. The standard way of performing a wind resource study has been unchanged since the 1980s, when the WASP program (linearised flow model) was developed as part of the European Wind Atlas project^{2,3}. All linearised models have proven successful in simple terrain, but performance fails in very complex terrain, which is where many wind turbines are currently erected. The European Wind Atlas method is also the main method to obtain financing for a project.

The obvious next step is to apply more advanced tools to wind energy assessment. But CFD flow modelling has not yet been verified and validated at a satisfactory level for wind loads and resources, and not enough full-scale experiments have been carried out that would allow for the proper validation of available CFD models suitable for complex terrain. Contrary to the aeronautical industry, wind engineering cannot demonstrate well-documented, good, comprehensive and accurate experimental data which may serve as the basis for model development. It is therefore necessary to acquire this data. A new Askervein experiment is recommended.

Calibrating advanced models: the Askervein experiment⁴

The Askervein hill study⁵, carried out in 1983, is one of the few real full-scale experiments which have included a test of these models. This study was restricted to a single, nearly Gaussian hill with moderate slopes, which is to say far from the complexity of the terrain where most wind turbines are located today. The extent of turbulence measurements in the Askervein experiment was rather limited by today's standards. In the early 1980s, the

² Troen, I. and Petersen, E. 1989: *European Wind Atlas*. Risoe National Laboratory, Denmark

³ Landberg, L. et al, 2003: *Wind-resource Estimation: an overview*. Wind Energy, 6:261-271

⁴ The original Askervein Hill project consisted of two field experiments conducted during September and October 1982 and 1983 on Askervein, a nearly Gaussian hill on an island in the Outer Hebrides of Scotland. This collaborative study of boundary-layer flow over low hills was carried out under the auspices of the International Energy Agency Programme on Wind Energy Conversion Systems. Fifty towers were deployed and instrumented for wind measurements. Most of the instruments were 10m cup anemometers but, in the 1983 study, two 50m towers, a 30m tower, a 16m tower, and 13 10m towers were instrumented for three-component turbulence measurements. Results from this experiment provided data which enabled the development of nearly all current linear flow models for the following 25 years

⁵ Walmsley, J. L. & Taylor, P. A.: *Boundary-layer flow over topography*. Impacts of the Askervein study Boundary-Layer Meteorology, 1996, 78, 291-320

Askervein field campaign was set according to the requirements of the time, mainly to validate linear flow models over gentle hills, with no flow separation. This experiment provided data that enabled the development of nearly all linear flow models for the following 25 years⁶. However, the data does not meet the requirements for the validation of today's more complex non-linear mathematical models.

Regarding the current need for improvement of accuracy and reduction of uncertainties, a follow-up to this historic experiment is necessary, preferably at several sites, including one offshore.

Data must be made available to the European research community for the calibration of micro- and meso-scale models, validation of CFD models (LES and RANS) and models for numerical weather prediction (including reanalysis), as well as remote sensing data acquisition. Onshore information such as relief, land use and terrain roughness or sheltering may be measured by optical and radar sensors on a satellite and communicated to users.

Such an experiment will also contribute to the establishment of good data-handling practices and the assessment of progress in measurement techniques. To this end, additional standards are needed.

Standards

While there is already an IEC standard for load calculations, the absence of a standard regulating the assessment of wind resources is a source of uncertainty and risk to wind energy projects. The first obstacle impeding an accurate and reliable estimate of the energy production of a future wind farm is the lack of consensus on the contents of a wind study, and the best procedure for carrying one out. A standard for wind resource assessment covering all or most cases (flat terrain, complex terrain and offshore) should be developed.

A.2 Offshore wind power meteorology

Meteorological conditions over the sea are different from those over land. The underlying surface for the air flow has very different characteristics and therefore interacts differently with the wind. This has important impacts on the heat, momentum and moisture fluxes between air and sea, which govern the flow. Atmospheric flow over the sea has been of minor importance to meteorological research so far, especially at those heights and distances from land that are important for wind energy utilisation. This is because there are far fewer human activities on the sea than on land. It is also partly due to the lack of suitable measurement data and the complexity of the physical processes.

For a massive utilisation of offshore wind for power production it is essential to develop new models or extend present ones, and to develop methods for determining design conditions, assess the wind resource, perform short-term forecasts, etc. This requires an improvement in meteorological knowledge of the air flow over the sea, especially in its interaction with the water, waves and currents. Measurements will play a crucial role in the development of this understanding in addition to their importance for wind farm development.

⁶ Castro, F. A.; Palma, J. M. L. M. & Lopes, A. S.: *Simulation of the Askervein flow*. Part 1: Reynolds averaged Navier-Stokes equations (k- ϵ turbulence model) *Boundary-Layer Meteorology*, 2003, 107, 501-530
Lopes, A. S.; Palma, J. M. L. M. & Castro, F. A.: *Simulation of the Askervein flow*. Part 2: Large-eddy simulations *Boundary-Layer Meteorology*, 2007, 125, 85-108

Methods and models for offshore wind power

Today's models for conditions on land are also used for the design of offshore wind turbines and the planning of offshore wind farms. Offshore effects are only taken into account by changing the models' parameters. Furthermore, short-term forecasting methods and models are not adapted to the meteorological conditions that characterise offshore locations. Offshore wind power creates a number of new challenges for wind power meteorology:

- Design conditions must be established for the offshore environment. Not only is the wind of great importance, but wave loads are too. Combined statistical descriptions for wind and waves are therefore necessary.
- Standard models and methods for offshore locations, incorporating the specific meteorological conditions offshore, will have to be developed for resource assessment and wind potential studies.
- Wind power forecast models for offshore sites must provide considerably improved accuracy to allow the efficient integration of offshore wind farms, where large installed capacity is concentrated in a small area. Longer time horizons are needed for maintenance planning at offshore locations.

Meteorological research

Our general knowledge of offshore meteorological conditions is insufficient. It is impossible to say, based on present research, to what extent current models need to be improved and to what extent new models will have to be developed. However, some insufficiencies are already apparent from the limited experience available:

- Waves and currents are usually only taken into account through general parameters; complete wind/wave/current models are not available
- The effects of the land/sea discontinuity on the flow (internal boundary layers, boundary layer height change) have not been sufficiently modelled
- The present models do not take sufficiently into account the increased importance of atmospheric stability over the sea
- Surface layer parameterisations of NWP and other meteorological models need to be improved for offshore locations
- Remote sensing from satellites is not sufficiently utilised. The use of near-online satellite measurements needs to be explored
- The height profile of wind speed over the sea needs a detailed description, including the influence of boundary layer height, internal boundary layers, low-level jets, atmospheric stability, wind/wave/current interaction and so on
- The presence of coherent turbulence structures over the sea, and their importance, need further investigation, as they might cause major gradients in power generation

Dedicated research measurements, covering the atmosphere, waves and currents, are necessary in order to provide a sufficient data base for research into these questions and for model development.

Close cooperation with meteorology and oceanography research communities is indispensable.

Measurement methods

The availability of meteorological measurements is of crucial importance for research as well as for the acceleration of the deployment of offshore wind power. Experience from offshore meteorological measurements and wind farms is very limited. So far, there are only a few offshore installations, and measurement data is very often commercially sensitive and thus not available for research. The amount of freely available (mainly publicly-funded) measurement data is extremely limited.

Tall meteorological offshore masts have proven very costly. Furthermore, flow distortions around the often very strong and bulky masts are an issue. Initial tests on ground-based remote sensing have been performed with promising results. However, the availability of data and its accuracy has to be improved and a standardised method for stand-alone long-term monitoring has to be developed. The possibility of using a floating structure has to be investigated.

Satellite-based remote sensing is a very promising method for obtaining offshore information (e.g. 10m height wind, waves, tide, currents or bathymetry) with varying spatial resolutions and accuracies.

High-resolution mapping of the offshore wind resource is in demand by the offshore industry. The expected spatial resolution allows the description of the wind's behaviour on a scale equivalent to the surface of a wind park. For an accurate estimate of wind climatology, high-temporal resolution data is needed in order to capture temporal wind variations. Some space-borne remote-sensing instruments may provide relevant information on offshore wind. In this regard, scatterometers and synthetic aperture radars (SAR) are of particular interest.

The main areas for improvement are:

- Satellite-based offshore wind measurements need to be validated extensively against in-situ measurements. In particular, their measurements of spatial variability and overall performance must be assessed. Accuracy, precision and quality must be improved and uncertainties reduced
- For satellite-based data, there is a need to communicate existing data sets and their limitations to the wind industry. There is also a need for education on what they are and how to use them

A.3 Wakes

Large multi-row wind farms are being developed, mostly in offshore areas or complex terrain. The first evaluation of large offshore wind farms suggests that standard wind farm models under-estimate future wake-induced power losses, suggesting the need for new approaches. Current predictions of power loss suggest 10-15% in large offshore wind farms, but the actual loss may exceed these figures considerably.

Most wind farm models use wake modules developed for small wind farms in the 1980s. The under-estimation of future wake losses seems to be linked to wind farm size, suggesting that models incorrectly parameterise one or more issues which might include turbulence, boundary-layer interactions and so on. A significant amount of research on complex terrain is needed in order to understand the behaviour of single and multiple wakes respectively. Spatially (multiple mast) and temporally highly-resolved measurements are still missing.

Models must reflect what is observed in terms of power losses and loads from wakes, so that wind energy developers have state-of-the-art tools at their disposal for optimising the layout of large wind farms.

A.4 Extreme wind speeds

An important parameter in the site assessment of a wind farm is the 50-year extreme wind, v_{ref} . The choice of different turbine classes according to IEC standards is mainly determined by this value, in combination with turbulence intensity.

However, the estimation of extremes is often associated with major uncertainties, mainly due to the lack of long time series from the location of interest. A proper statistical estimation of the 50-year wind typically calls for 10 years of data, and very often this is not obtainable. A reduction in uncertainty may be achieved by introducing an extreme wind atlas, based on reanalysis data in combination with meso-scale modelling and a final downscaling to the point of interest.

The need for a global extreme wind atlas is also apparent if one looks to the current European Wind Load Code (Eurocode). Each country in Europe has established a procedure of its own when it comes to using the measurements of surface winds to evaluate extreme winds, and this has led to a significant discontinuity of wind speeds along the national borders, see e.g. Miller (2003). For instance, the 50-year wind is 24 m/s in south-east Denmark but 32 m/s in northern Germany. Taking into account that the forces (and in some cases also the price of a structure) increase by the square of the wind speed, this is a significant and unrealistic difference.

Besides extreme wind speeds, defined as 50-year events and measured as maximal wind speed magnitudes, we also have extreme wind changes. An increase or decrease in wind speed of more than 10 m/s for one second will cause high mechanical loads and fast power fluctuations. Currently, these gust-like events occurring at intervals of a few days during strong wind situations are not characterised by any classification scheme or model, and the frequency of this phenomenon is highly under-estimated.

Statistical methods for determining the extremes by means of time series have been investigated in large detail, e.g. Method of Independent Storms (MIS), Peak Over Threshold (POT), and Annual Maximum Method (AMM) including both standard and generalised Gumbel methods. The AMM tends to provide an upper boundary for v_{ref} based on time series of approximately 10 years⁷. Common to all these methods is that the lower the number of samples in the time series, the greater the uncertainty, and we therefore need means or methods of extending the length of time series.

Attempts such as Wasp Engineering have been made to create an Extreme Wind Atlas⁸ but validation is still needed with respect to the resolution of the various types of reanalysis data, e.g. NCAR/NCEP, REMO and so on.

v_{ref} is based on a 10-minute averaging time and until very recently, research has not dealt with the sampling methods, i.e. sampling interval and averaging times, which in analysis of

⁷ Ying An, M.D. Pandey, *A comparison of methods of extreme wind speed estimation*, J. Wind Eng. Ind. Aerodyn. 93 (2005) 535–545

⁸ <http://www.waspengineering.dk>

extremes show a significant bias of up to 15%⁹. The models developed for calculating the bias need to be validated, which is an important part of the investigation for downscaling reanalysis data to on-site extreme winds.

The wind description currently used is based on ten-minute average mean wind speed values and the turbulence degree, or variance. Just like standard wind field models, this description is based on Gaussian statistics, which under-estimate the frequency at which large and fast wind changes occur by probability factors of one million to ten billions. There are no systematic investigations or research on this topic.

A.5 Wind profiles at heights of above 100m and advanced measurement techniques

Recent analyses of measurements of wind profiles over land (Høvsøre) and sea (Horns Rev, Fino) show that the height of the boundary layer is key to the understanding and description of the wind profile in the entire boundary layer.

The wind profile above the surface layer (50 – 80m) – even over flat terrain – is not well-known and the influence of the state of the atmosphere above the boundary layer is largely unknown. The focus should be on the wind profile for the entire boundary layer and the parameters used to describe it, including its height. Traditionally, the wind profile is described by surface parameters only, but additional parameters should be considered at the top of the boundary layer¹⁰, and their influence on the wind profile assessed.

An in-depth knowledge of the wind profile is necessary. This will be supported by the development of meso-scale Computational Fluid Dynamics (CFD) models (RANS and LES), and advanced measurement techniques enabling an accurate estimation of the wind field at great heights. The more generic field of wind measurement instruments is expected to evolve significantly with the emergence of remote sensing techniques.

Status of ground-based remote sensing

Wind measurements are traditionally obtained from tall meteorological masts, equipped with calibrated cup anemometers and/or sonic anemometers, with the following limitations:

- The data is reliable, with an uncertainty of less than 1%, but the height of meteorological masts is usually limited to 60 to 80m, due to the cost of these devices and cost of installation, particularly offshore
- In complex terrain, the influence of flow inclination and turbulence is high. Taking into account all sources of uncertainties, the global uncertainty is higher than 1%
- As rotor diameters increase ($\varnothing > 100\text{m}$), the wind shear over the vertical extension of the rotor is significant. Upwind measurements in a single point at hub height are insufficient

These limitations have raised interest in the remote sensing techniques applied to the wind energy sector. These technologies cover a large range of applications, from wind resource

⁹ Larsén and Mann (2007)

¹⁰ Potential candidates for the new parameters are the Brunt-Vaisala frequency (vertical temperature profile in the free atmosphere) as well as baroclinicity (horizontal temperature gradient) or subsidence

mapping at different spatial and temporal scales, to wind profiles or terrain roughness measurements.

Sodar devices have been used extensively over the past decades for the mapping of local wind resources from ground-based platforms. Operationally, Sodars show a good level of correlation with cup anemometers (90-95%) - their use is limited during strong winds ($> \sim 15\text{m/s}$), and their vertical range is reduced when there is neutral stability. Measurements can be disturbed by nearby obstacles such as masts or trees. However, large differences in data quality have been observed among the Sodars currently available, depending on their technology. Some of them have proven able to measure winds of up to 18-20m/s at 80m above ground level. This technique is still evolving, and significant improvements have been brought in by the manufacturers: multi-wavelength emission, multi-beam emission, frequency coding and software efficiency in noise reduction.

Up to now, Lidar technologies have been limited. Wind profiling and resource assessment using single-beam mono-static Lidars over complex terrain are impaired by inhomogeneities in the flow field. The maximum heights that can be measured by Lidar are currently limited to $\sim 150\text{ m}$. The picture is changing, as in 2007 the first commercial wind Lidars for wind resource assessment emerged on the market (Leosphere's Wind Cube; QinetiQ's ZephIR), enabling accurate remote sensing of vertical wind profiles in heights between 0 and 150m, some of these (QI's ZephIR) with an accuracy and a reproducibility of more than 99%, compared to cup anemometer-based profiles. Furthermore, a horizontal mean wind field mapping is accessible today by means of ground-based remote sensing (Lidar) at ranges of up to several kilometres (cf. Lockheed Martin's Windtracer, for example).

These advanced measurement techniques are expected to provide services to the wind industry such as wind turbine control, performance optimisation, power curve evaluation, or turbulence and wake modelling. This development should be promoted through the development of standards.

A.6 Short-term prediction

The latest systems (e.g. Anemos) use one or more types of meteorological input, time series of wind speed and direction, and possibly more data (e.g. vertical heat fluxes). From data in connection with the sampled SCADA data of the studied wind farm or region, the system builds a horizon-dependent power curve. A new forecast for the 48 hours ahead or more is produced each time a new meteorological or SCADA input is detected. In parallel, the system computes the forecast uncertainty (quantiles). The best systems have a Root Mean Square Error of 6% of the installed capacity when applied to a region like Germany. They are less reliable in difficult terrain, where weather predictions are not as dependable.

The limitations are:

- The systems require a cost function for tuning. Therefore they do not give the best forecast for a client who needs specific data
- Forecast accuracy and uncertainty must be improved. For example, an instantaneous error of 50% represents a potential variation equivalent to the production of 10 GW for a country like Germany (for an installed capacity of nearly 20 GW in 2006)
- Not all information enclosed in the meteorological forecast is exploited. The coupling between numerical weather prediction and short-term prediction models must be

improved. In the long term, dedicated modules for wind power forecasting will be integrated into weather forecasting models

B Wind power systems

B.1 Introduction

This section includes the wind turbine itself, the interaction between wind turbines in a wind farm, the electrical infrastructure inside the wind farm and installation and transport issues as far as land-based wind turbines are concerned. Offshore transport and installation is addressed in the section *Offshore deployment and operation*. This also applies to operation and maintenance issues. Figure 1 illustrates the way the corresponding Working Group interacts with other Working Groups.

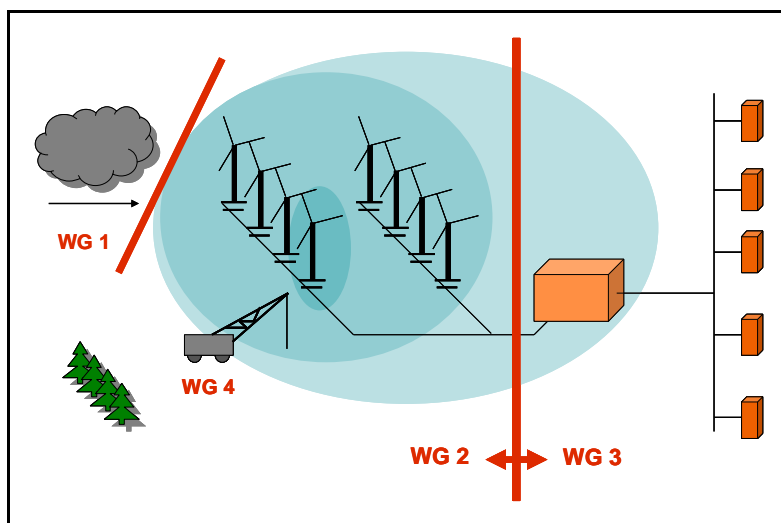


Figure 1: Interfaces with other Working Groups

B.2 Research approach and strategy

Short-term problems that impact existing wind turbine technologies require a fundamental approach in order to fully understand the cause of the problem. Classifying research as applied or fundamental, short-term or long-term is not relevant.

For public R&D funding, it is important to identify those research needs that require an in-depth, fundamental approach, which the industry itself is not able to provide. This is because research needs have too high a risk and a pre-competitive character.

The proposed classification of R&D is illustrated in Figure 2. Only applied research is considered. The research is divided between activities aimed at 'incremental improvement' and activities which are 'innovation-orientated.' Only research that requires a fundamental approach is considered.

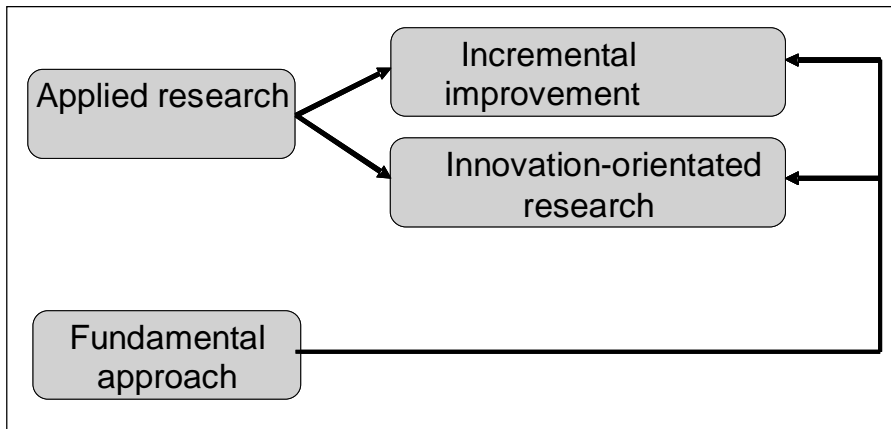


Figure 2: Research types

In order to establish large production volumes, several pressing demands (such as securing adequate supply chain, managing the volatility of cost of raw materials, securing expertise and manpower, securing grid integration capacity, manufacturing capacity, development capability and technical reliability) have to be met. This can be done through a strategy focused on producing continuous, incremental improvements in the current basic concepts of wind turbine systems. By concentrating on incremental improvement only additional opportunities for technology improvement might be missed: innovative concepts which can potentially cause a drop in the cost of wind energy. The offshore sector in particular is pressing for new designs which are fully dedicated to offshore applications. The two strategies should be developed in parallel.

This dual approach is illustrated in Figure 3, through the evolution of maintenance costs as a function of lifetime concepts. Typically, maintenance and repair costs increase immediately after a new concept is put into operation. Through incremental technological improvements, the maintenance and repair costs decrease. For an innovative concept, it is likely that the learning trajectory would have the same characteristics.

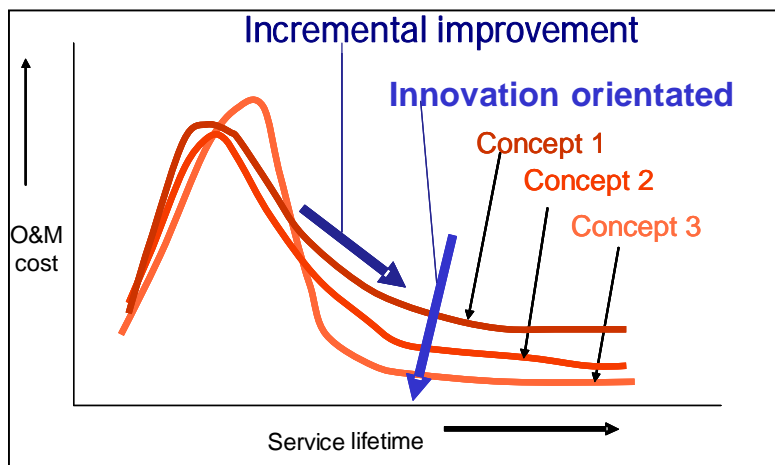


Figure 3: Illustration of incremental improvement and innovation-oriented research

It is irrelevant to rank the topics individually without taking into account their mutual relationship. Instead, funding priorities should be established, based on the potential

contribution of a research activity to the reduction of Cost of Energy (COE). The COE is defined as follows:

$$COE = \frac{(FCR \times ICC) + AOE}{AEP_{Net}}$$

Where:

- COE is the levelised Cost of Energy (€/kWh),
- ICC is the Initial Capital Cost of the project (€),
- AEP_{Net} is the net Annual Energy Production (kWh/yr),
- FCR is the Fixed Charge Rate (1/yr),
- AOE are the Annual Operating Expenses (e.g. O&M, replacement, land).

The research objectives are defined to minimise the COE value by finding the optimal balance between decreasing the ICC and AOE parameters, and maximising the AEP value. It should be realised that this formula does not reflect the value of wind energy (represented as the price of wind energy). Increasing the capacity factor of a wind turbine system has a positive impact on the capacity credit and helps lower the balancing costs of the electricity grid. These effects have to be considered separately.

The current state of play is assessed below. The objectives are divided according to the major disciplines and technology areas:

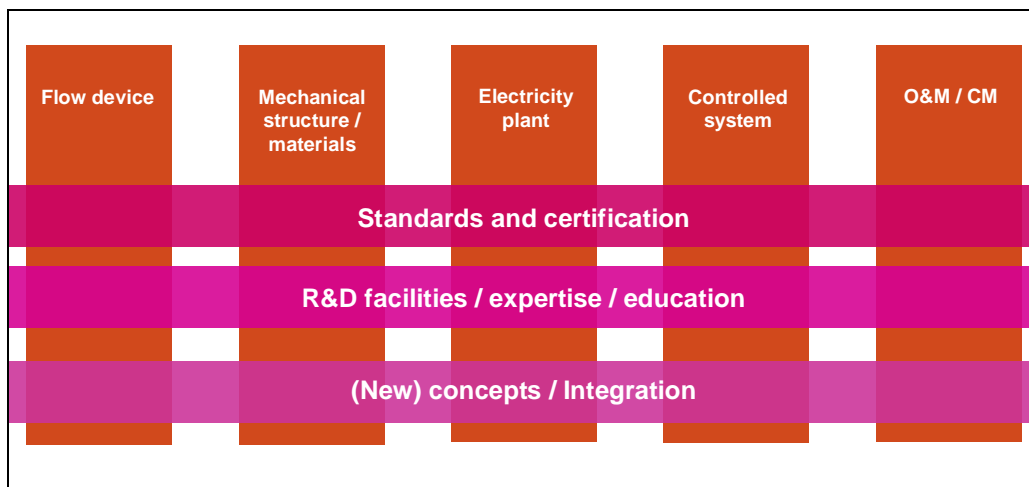


Figure 4: Priority areas

B.3 Wind turbine as a flow device

Design tools for wind turbines of up to approximately 50m in diameter currently come under a reasonable amount of verification. With the increasing size of rotor diameters, new design codes should be developed, including aerodynamic and aero-elastic phenomena currently not taken into account.

CFD tools are currently being developed into the design codes of the future. Once developed, experimental verification for virtually all new design tools needs to be carried out. As external flow conditions need to be taken into account, this should be implemented in collaboration

with the research agenda of the section *Wind conditions* under the priority *siting in complex terrains*.

B.4 Wind turbine as a mechanical structure/materials

Loads

Although there is a basic knowledge about the loads during operation, in practice component manufacturers are not satisfied with the manufacturing specifications. Disputes frequently arise about the cause of failures, and it is often difficult to assess whether a failure is caused by insufficient specifications or poor manufacturing.

Materials

In upscaling, the industry faces the need for blade materials which combine lower costs with a higher strength to mass ratio compared with materials currently used. These materials are not available at the moment. Alongside accurate descriptions of operating loads, a continued characterisation of both existing and new materials is therefore needed to reduce design safety factors and costs. Because there are a few uncertainties in material characterisation, improved methods of measurement and evaluation are also called for.

Moreover, new materials could make the cost of a wind turbine less dependent on the volatile market prices for steel and copper.

Finally, recycling methods (e.g. the use of thermo-plastics for blades) for components and materials should be investigated so that the quality of the materials can be maintained at original levels after separation and recycling.

Drive trains

The industry recognises that there is a lack of knowledge of the dynamics of drive-train behaviour that would enable current problems to be fundamentally resolved. A full understanding of drive-train mechanics is needed in order to resolve gearbox and main bearing problems.

The reliability of drive trains could be improved through online condition monitoring systems with related fault prediction algorithms. Condition monitoring and system control could be improved considerably by incorporating sensors into (innovative) materials.

This knowledge would enable new drive train concepts for large wind turbines and extreme external conditions to be developed, notably for offshore applications.

B.5 Wind turbine as an electricity plant

Virtually all modern wind turbines include power electronic conversion systems, which enable variable speed operation (higher system efficiency and reduction of dynamic loads), control of power quality (reactive power supply, voltage control, minimising injection of higher harmonics in the grid) and additional control possibilities via the electrical conversion system (active vibration damping, lower rotational speed for reducing acoustic noise during critical periods).

Further cost reductions can be achieved by developing power electronics which work on higher voltage levels. In such a way, transformers could be avoided and could be smaller (smaller transmission ratios) and thus cheaper.

Most of the generators are high-speed synchronous generators which need gearboxes between the rotor and the generator or directly-driven, low-speed, generators. The advantage of direct-drive generators (no gearbox needed) could be further enhanced by making the generators less material-intensive by applying permanent magnets and introducing super conductivity. New generators are being developed on rather a modest scale. The research on super conductors in wind turbine generators yet has to start. Significant improvements could be made by accelerating and intensifying the development efforts.

In the future, the number of wind turbines that constitutes a wind farm will increase considerably. Furthermore, the distance between turbines will increase as the size of wind turbine rotor diameters goes up. New infrastructure for connecting and transmitting electricity from the individual wind turbines to the transformer station and onward, will probably lead to significant cost reductions. These developments should also include new cabling for different voltage types (AC versus DC).

B.6 Wind turbine as a control system

The first generations of wind turbines only had limited control abilities, such as basic rotor speed and power output control.

As the size of the turbines increases, material stresses increase and the structures become more compliant. If measures are not taken to prevent this, the level of structural vibrations and dynamic loads of the entire wind turbine structure, including the support structure, will increase. One way of avoiding this is by incorporating active damping through the generator system and other control systems, such as aerodynamic devices attached to the blades. While performing such control tasks, the system should also carry out its original task - optimising power performance. The control strategies should therefore be smart, adaptable to changing external parameters, and include distributed aerodynamic rotor control.

The development of sensors and computers could provide opportunities to find multi-parameter, adaptive-control methods that can optimise the way the turbine operates. This means that the entire range of critical parameters that influence efficiency, capacity factor, safety, power quality, structural and electric stability is continuously controlled, while external conditions and turbine properties may vary. These methods can be implemented by using extremely reliable, durable and accurate sensors, guaranteeing low operations and maintenance (O&M) costs over the lifetime of the turbine. These sensors are not available yet.

B.7 Innovative concepts and integrated design

Today, different design packages are not fully compatible with each other. It is therefore not possible to consider the system as a whole in the design phase. In terms of system optimisation, it implies that partial optimisation is performed on sub-systems. This local optimisation is unlikely to be equivalent to the result of a global approach to optimisation.

Integral design methods should include, for example, sub-design routines such as those for blades, power electronic systems, mechanical transmission, support structures and transport and installation loads. These methods should be thoroughly verified during their development, and introduced into the standard design and certification processes.

Many of the necessary elements for an integral design base are available. However, the existing knowledge is not fully applied. Future research should therefore not only focus on

improving the methodology, but also on improving wind turbine manufacturers, component manufacturers and certification bodies' access to the most recent information.

Given the huge challenges in the current and medium-term markets caused by the gap between supply and demand, the first priority is to improve existing wind turbine concepts, but as Figure 5 shows, this should not prevent the exploration of innovative concepts, as these can potentially cause a drop in the cost of electricity. For each type of environment (offshore, extreme sites on land), specific concepts might be needed. These new concepts will arise from innovations in materials and components.

Innovative concepts can be based on the numerous wind turbine concepts and components developed in the past. Prototypes were built and tested but were never applied by the industry because of uncertainties and lack of proof of concept. After the wind turbine market boomed, these activities were either abandoned or became a more low-key activity in R&D establishments and academia. The present market situation (up-scaling, large wind farms, over 20% penetration of wind power in the grid, extreme sites) and its prospective development make it necessary to re-evaluate the findings of the past and the potential for a technology breakthrough. Proof of innovative concepts should be given through public-private partnerships by means of joint research, development and demonstration actions.

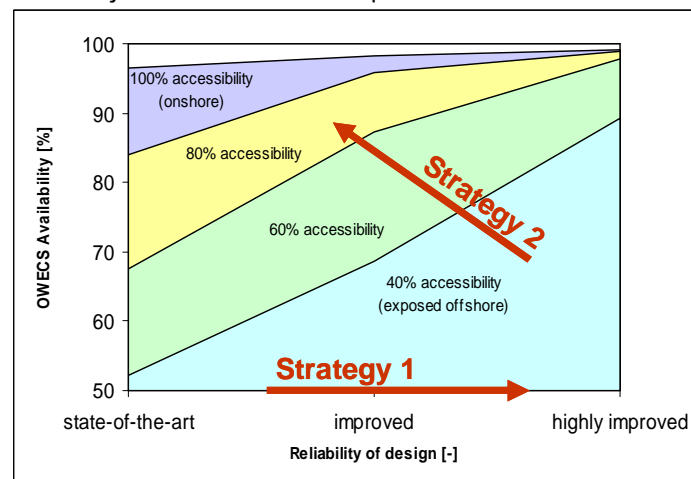


Figure 5: Availability as a function of reliability and accessibility. Strategy 1 is dealt with in the current section, while strategy 2 is focused on the section entitled *Offshore deployment and operation*

B.8 Operation and maintenance

Today, O&M strategies are based on periodic inspection and (often non condition-dependent) replacement of wind turbine components. Fault statistics from existing wind farms are either unavailable or insufficient. O&M strategy could be improved through a reliable estimation of the components' remaining lifetime, and a greater knowledge of fault statistics and their consequences and development over time. This should be supported by extensive monitoring. In addition, maintenance has to be minimised through the introduction of preventative maintenance strategies and tools that have been developed on the basis of low cost and extremely reliable condition-monitoring methods.

In parallel, the global reliability of the system should be improved, as should wind farm management, wind turbine components must become extremely reliable and wind turbines must survive at least one power failure.

C Wind energy integration

C.1 Wind power plant capabilities

Grid code requirements

In this field, the limitations are the following:

- Grid code requirements were often written for conventional forms of power-generating technology, and cannot be directly applied to wind turbine technology
- The existing terminology and concepts have often been developed differently in different European countries
- The circumstances and system characteristics under which each ancillary capability is required are not defined
- Although it is necessary to standardise terminology and concepts, it is currently believed that the numerical values of the requirements (parameters, limits, set-points etc.) do not require standardisation across Europe, and are likely to vary from system to system, depending on the system's characteristics (for example, the British system has a lower equivalent inertia than the UCTE system, and therefore requires faster frequency control). Numerical values for the requirements (parameters, limits, set-points etc.) should be calculated for each system, depending on the system characteristics
- Compliance of the wind turbines with the requirements should be verified. This involves specific wind power plant capabilities and methods, and is likely to require the development of standards for testing at different scales (such as components, complete wind turbines and installed wind farms)
- To enable the management of large-scale fluctuating production, standardised IT services from wind farm operators to Transmission System Operators (TSO) (e.g. production monitoring and forecasting) are needed, but these are not yet fully available

For all the above topics, it is necessary to consider economic and financial factors. In other words, each requirement should take the costs and benefits to system operators, wind power plant operators and other connected customers into account. In this way, agreement on technical issues should be reached through the appropriate R&D, which should then reduce or remove the need for an attempt to harmonise existing national practices on a political level.

Ancillary services are discussed separately for the major categories of capabilities, as each one has its specific issues and problems. However there is also the general issue of agreeing on concepts, definitions and methodologies between network operators, wind farm operators and wind turbine manufacturers in order to provide common ground across Europe and avoid wind turbine manufacturers having different designs for different countries. Note that the aim is not to fully standardise requirements - this is not desirable, as there are significant differences in the characteristics of electricity systems and wind penetration targets across Europe.

Active power control

In principle, all pitch-regulated wind turbines can control active power. Moreover, at wind farm level or superior control levels like wind farm clusters, wind plants can develop different active power control strategies such as balance control, delta control, active power curtailment and ramp rate control using central wind farm controllers.

Active power control can also be used to provide contributions to frequency control. Only a few manufacturers currently provide this, and the requirements vary from country to country. In order to provide frequency control, the wind turbine's active power must increase or decrease with system frequency changes. Thus for low-frequency response, it is necessary to de-load the wind turbine, leaving a margin for an increase in power. Variable-speed wind turbines can be de-loaded using pitch-control action or by using the variable-speed electronic controller. The costs of frequency-control services should take wind power plant de-loading into account.

However, not all manufacturers of pitch-regulated turbines have included the communication and control functions that will allow active power limits to be set or active power rate-of-change. In addition, most grid codes give only steady-state requirements, and do not define the dynamic requirements adequately (such as speed of response or accuracy).

Voltage/reactive power control

Voltage/reactive power control from wind turbines is important due to the distributed nature of wind turbines and because wind farms are sometimes located away from strong grid connection points. In order to minimise reactive power flows within the wind power collection network, and to maintain a reasonable voltage profile, individual wind turbines should have voltage control or a power factor correction capability.

Most wind turbine technologies can provide voltage/reactive power control, and for those that cannot, additional reactive-power compensation equipment can be installed to meet the requirements. In principle, if reactive power can be controlled, then the wind farm can also contribute towards voltage control.

However, not all wind turbine manufacturers can currently cater for the significant variation in country-specific requirements for voltage/reactive power. In some countries there are dynamic requirements (speed of response) that require special communication capabilities within the wind farm that most wind farms do not have.

Fault ride through (FRT)

This is the ability of the wind farm to continue to operate during and after a major network fault. This function is required by many TSOs in order to avoid a major fault that causes a sudden loss of large amounts of wind generation over a large area. Today, most wind turbines can provide FRT capabilities. In some of the European countries which started implementing wind power early, a large number of wind turbines without FRT are still in operation (in Germany and Denmark, for example). Here, the value of retrofitting has to be assessed.

The major steps to be taken are defining the requirements satisfactorily and defining a method of proving compliance, which would build on the ongoing work within IEC (61400-21) and IEA Wind Task 21.

Other power plant capabilities

Contribution to system inertia

A control system for variable-speed wind turbines works by applying a restraining torque to the rotor according to a pre-determined torque-rotor speed curve. The aim of using this control system is to get a maximum-power extraction. This control action is de-coupled from the power-system frequency. Therefore, unlike conventional synchronous generators, wind plants do not contribute to system inertia.

With a large number of wind turbines in operation, the angular momentum of the power system will be reduced because some conventional synchronous plants will not be operating. Hence the system frequency may become more sensitive to sudden variations in load. Therefore, it is important to develop methods of reinstating the effect of machine inertia on wind turbines.

Black start

A black start is the process of restoring a power station to operation after a power cut has occurred over a wide area. Wind turbines cannot usually perform black start, and wind farms are not used for this purpose at the moment. Also, not all conventional generation plants are able to perform black start either and it is not likely that this will change in the future. Therefore, careful consideration should be given to whether it is practical and feasible to perform black start with wind farms instead of other generation plants (e.g. hydropower). This could be an R&D topic for future high-wind penetration systems.

Damping (power system stabiliser)

The basic function of a power system stabiliser (PSS) is to add damping to the synchronous generator rotor oscillations. Most variable-speed wind turbines operate using a dq-based controller. It is worth exploring the possibility of redefining the power system stabilisation in the dq frame. Further investigations into the design and implementation of PSS in the dq reference frame and into the tuning of a PSS on a generic network are required.

Other issues

It will become necessary to know how many ancillary services can work at the same time and to know which ancillary services should be provided to help the network in a right way, taking into account factors such as the technical restrictions and regulatory restrictions. It means that there will be a control system which should analyse these aspects and choose the most efficient strategy. The system also should send suitable set points to individual wind farms or groups of wind farms in real time. This control system should fulfil two main requirements: stable networks and maximum wind production. The control system may be distributed.

C.2 Grid planning and operation

Grid extension and reinforcement

At European level, TSOs are increasingly working in a coordinated way in order to support the European Commission in creating the Integrated Electricity Market (IEM) while maximising security and minimising the costs of electricity supply. There are common TSO working

groups for issues such as coordinated planning, congestion and security management, and market-coupling concepts. There are also joint investigations into wind energy integration in Europe, such as the European Wind Integration Study (EWIS). In this context, the European Commission is demanding an accelerated grid extension, especially new interconnection lines. But the European Commission has not yet provided the required legal framework for the adaptation of the various national rules. So, despite the existing European guidelines for Trans-European Energy networks, various national and local rules, as well as public resistance, are slowing down grid extension and reinforcement measures.

Currently, most system operators design their systems on deterministic rules that have resulted in highly reliable electricity systems in the past. However, as wind generation has different characteristics to conventional generation, in particular a lower capacity factor than conventional power plants, these deterministic rules may result in major reinforcement of the transmission system in order to accommodate wind. This has two problems:

- It may not be economically justified, as wind production (especially the sum of wind capacity across a large region) will only rarely reach its nominal capacity, unlike conventional generation. It may be better to use probabilistic analyses resulting in less transmission reinforcement and an occasional curtailment of wind production. For situations where curtailments would occur frequently, grid reinforcement is unavoidable
- The timescales for the construction of transmission reinforcement are long (typically 10 years for a major installation) and uncertain (due to the need to follow local permit procedures). This alone may prevent several European nations from achieving their renewable energy targets

Operating the grid

While grid reinforcement and expansion are necessary, it is also important that existing grid infrastructure is used in a better way, maintaining system reliability (security of electricity supply).

This requires the employment of artificial intelligence and probabilistic analysis-based tools for real-time operation. If overloads are detected early, they can be avoided by advanced control of wind farms and wind farm groups. At European level, the increased complexity of the grid needs to be balanced by better supervision and operation that make use of wide area monitoring and control (WAM&C) and wide-area protection (WAP) systems. A Europe-wide Dynamic Security Assessment (DSA), based on extensive data-sharing between control zones, should assist grid operators in real-time operation.

For those TSO control areas which are affected by high wind power infeed, maintaining the security of electricity supply can be very challenging, especially if the individual control area is small: where there is a strong wind power infeed, some conventional power stations should remain connected to the grid to maintain sufficient control reserve capacity. Due to the continuous increase in installed wind power, not only a national but a Europe-wide physical distribution of wind energy will become necessary in order to maintain the security of electricity supply.

C.3 Energy and power management

There are varying procedures in different European countries and power systems for managing wind power at the moment. Currently, wind energy is managed by TSOs or producers as part of their portfolio. Wind forecasts are widely used and have been improved considerably during the last decade, with ongoing active work in the sector. There have been situations with high wind power infeed at low loads that have caused curtailment of wind power. The key issues are:

- There is not enough emphasis on the European aspect of energy management systems. A stronger focus on this would help variations in wind power to be internationally balanced and levelled out. Energy management systems should be part of the international dimension of future power markets
- There is insufficient interconnection capacity to make use of geographical spreading of wind power
- There is often insufficient wind power generation information available online for TSOs. The collection of data and its use in the management of power systems should be included in the tools available for TSOs
- There is a lack of tools that support the interaction between wind power, other RES, storage and demand-side management
- Wind power forecasts still need to be improved, especially for extreme cases. Forecasting, using constantly updated information and uncertainty estimates, should be integrated and implemented into operational tools
- The long-term objectives for wind power are unclear. There is no central incentive scheme, and those incentive schemes that do exist often do not include market signals ('prioritisation') which are essential for promoting the use of elements of wind power plants other than 'energy delivery'
- Integrating wind power into the long-term planning of TSOs: the variability of wind and forecast errors at different time scales should be assessed. Simulations should be performed at European level, and scenarios for future power systems in the period 2020-2030 shall be studied
- Rules and regulations are different in different countries. R&D is needed to determine the dimensioning parameters for reliability
- Wind power's compatibility with microgrids should be investigated with regard to rural electrification

D Offshore deployment and operations

D.1 Common themes

Safety

The safety regimes for offshore wind farms across Europe are in their infancy. They are loosely based on national onshore safety regimes for wind turbines, augmented by offshore experience from other jurisdictions such as marine, oil and gas. Because the national regimes are still under development, there are gaps in the secondary regulations that define how they should operate. This forces operators to return to the primary legislation and to develop their own interpretation as to how the legislation should be implemented. This causes significant variations in standards within each jurisdiction in addition to the already substantial variations between jurisdictions.

The offshore wind industry will become a pan-European industry with people and equipment moving across national borders. The application of different standards, philosophies and regulations in each of the Member States will increase costs and reduce efficiency and could impact safety. Furthermore, in many jurisdictions the industry and the authorities have concentrated on the regulatory regime for construction, leaving the operating regime vague. This may be the area of greatest uncertainty and where the biggest improvements are required.

Education

As stated in the section entitled *Human resources*, the potential of the offshore wind industry has not yet been fully appreciated by students or educators. The industry is on the cusp of commerciality, but neither the engineers and technicians nor the programmes to develop them are available. The initial development of the offshore wind industry will require the redeployment of engineers and technicians from other industries and will require basic safety and familiarisation training to be developed rapidly.

Environment

Europe has developed clear objectives for the conservation of natural habitats and for the development of significant offshore wind resources. Experience has shown that regulations developed both at European and at a national level to meet these objectives are in conflict. The development of the industry is being severely hampered by complex and inconsistent European and national policies. The failure to provide clear and consistent planning and regulatory frameworks is delaying projects and increasing costs and risks.

Finally, a serious threat to offshore development comes from the military sector, which has concerns about the impact of offshore wind turbines on national defence radar.

D.2 Substructures

The offshore manufacturing business was developed by the oil and gas industry to supply a limited quantity of bespoke structures. It established a number of facilities around Europe to manufacture these structures and over the last 40 years it has built several hundred of

them. However, as oil and gas technology have moved towards subsea developments, the offshore manufacturing capacity has been significantly reduced.

The offshore wind industry will need to deploy upwards of 20,000 structures in the next 10 years. The offshore manufacturing business cannot deliver this in its current form. The industry has insufficient capacity, and the processes adapted from oil and gas sector are not capable of delivering the volumes required.

D.3 Assembly, installation, and decommissioning

As explained above, the offshore wind industry will install upwards of 20,000 structures in the next decade. There is insufficient capacity in the industry to undertake this task and the current installation vessels and methodologies are incapable of meeting the challenges of the future. The vessels are unable to operate in many areas that will be developed in the coming decade or can do so only within limited weather windows. The design of the existing installation vessels, the installation methodologies and the equipment used are not sufficient to allow Europe's offshore wind targets to be met.

D.4 Electrical infrastructure

The limitations of the national grid systems, and their extension to the offshore environment, present a major challenge to the offshore wind industry. The putting into place of the in-field cables proved to be a high-risk area during the installation of the first generation of offshore windfarms. This problem has been compounded by shortages of people, equipment and vessels.

D.5 Turbines

Current offshore turbines are adaptations of onshore designs. As yet, they have not fully addressed the major challenges of the offshore environment, such as marination, corrosion, reliability and maintainability. In addition, there is a shortage of turbines suitable for the offshore market as the new generation of machines is about to enter serial production. There is a shortage of facilities for testing new equipment and ensuring that it is suitable for offshore deployment.

D.6 Operation and maintenance

The performance of offshore wind farms is severely impacted by the poor reliability of the turbines, compounded by access difficulties. Even small failures can cause major production losses as operators cannot get to the machine to restore it to production as the existing ways of accessing offshore turbines are severely weather-dependent.

The current generation of turbines was not designed for offshore use and it is unlikely that these turbines can be easily maintained in a remote offshore environment. Furthermore, offshore operations and maintenance strategies are in their infancy, further reducing productivity and increasing costs.

D.7 Budget

The market deployment and research actions have been grouped to develop activity areas for the common themes and the key priorities. The actions have been simplified and combined into key activities and these have been split into demonstration, deployment and research. So although an activity may have been classified as deployment, it may encompass some research activities as well.

The total budget for all of the activities is €273 million, which is spent mostly on demonstration and deployment activities: circa €100 million for each (40% of the total budget). The research budget is smaller, but still substantial at €58 million or 20% of the total budget.

The tables below summarise the budget by category and detail the percentage of expenditure for each activity. A detailed breakdown of the budget by activity and period is also provided.

Predominant activity	Budget in period (€million)			Total (€million)	Percent of total budget
	Short-term	Medium-term	Long-term		
Demonstration	36	30	44	110	40%
Deployment	35	42	28	105	38%
Research	13	22	23	58	21%
Total budget	84	94	95	273	

Priority	Category	Budget in period (€million)		
		Short	Medium	Long
Common Themes				
Design, development and demonstration of two access systems/vessels	Demonstration	5	5	2
Ecological and climate monitoring programmes at 10 demonstration sites in Europe lasting up to seven years	Demonstration	20	10	5
Policies and standards for health, safety and environment	Deployment	2	4	3
Geotechnical database and analysis techniques	Research	1	3	1
Training and education	Deployment	5	5	5
Substructure				
New and improved manufacturing processes and procedures	Deployment	4	3	0
New and improved manufacturing technologies	Deployment	4	3	0
Structural performance measurement programmes at demonstration sites	Demonstration	10	5	2
Develop, engineer and demonstrate floating designs	Research	0	5	10
New concepts and improved design	Research	2	2	2

Assembly, installation and decommissioning				
Improved design and development of vessels and equipment and extension of the operating window	Deployment	3	3	3
Development and optimisation of safe, efficient, reliable and repeatable processes	Deployment	3	5	3
Deepwater demonstration project	Demonstration	0	0	30
Electrical Infrastructure				
Development of better infield cabling design, improved cabling technologies and installation processes	Deployment	3	3	3
Development of the systems and technology for an offshore grid and its integration into the European electrical system	Deployment	5	10	5
Turbines				
Development of offshore test facilities	Demonstration	1	10	5
Improved understanding of wake effect and offshore array layout	Research	3	5	3
New and improved turbines for offshore use	Research	5	5	5
Operations and maintenance				
Design and development of vessels and equipment to operate and maintain offshore installations	Deployment	3	3	3
Development of maintenance strategies and management systems to maximise production and minimise costs	Deployment	3	3	3
More easily maintained offshore machines	Research	2	2	2
Grand total		84	94	95

E Enabling market deployment

E.1 Removing electricity market barriers

Wind power is traded on several European electricity markets by TSOs or producers as part of their portfolio. The key issues are:

- Markets are now designed with long gate-closure times and high penalties for imbalances. Operating in day-ahead markets means there will be high prediction errors and imbalances for wind power producers, especially for individual producers. Imbalance penalties can result in the total sum paid by individual producers being higher than the real imbalance costs in the power system.
- There is a lack of international markets, especially for intra-day trade, as well as real-time balancing markets. International trade is difficult for day-ahead and even more for intra-day markets. However, the situation is improving as the spot markets are better integrated at European level
- Markets do not provide incentives to demand-side management and flexibility use from all generation units. This is needed to keep the imbalance costs down
- It is difficult for smaller actors/producers to participate in the markets due to lack of IT tools and knowledge of the legal framework, high costs and unfair market designs. It is difficult for distributed wind power to get access to the power market
- Market nomination tools would be needed in order to integrate wind power and other generation, demand and storage from all over Europe to a tradable product

E.2 Creating a level playing field

The ExternE project¹¹, started in 1991, was the first comprehensive attempt to use a consistent 'bottom-up' methodology to evaluate the external costs associated with a range of different fuel cycles. Several studies have been carried out since then on the external costs of energy generation. Although it would be valuable to continue this detailed research, it is imperative that the findings of these studies are quickly reflected in energy pricing.

Studies are available which forecast the cost of technology development and the price of electricity from wind energy technology. However, it would be helpful to the industry if future studies would consider the effect of economies of scale on the industry in more detail, with reference to the latest target-setting at European level for a 20% renewables contribution by 2020, and also in light of the developments supported by this Strategic Research Agenda and Market Deployment Strategy.

Studies on the internalisation of the externalities of different energy resources are also available at national and European level. However, these would be more helpful if they were updated to reflect current cost prognoses and also to look closer at implementing the necessary changes in the price structure. Furthermore, analyses of practical ways of internalising externalities would help create tools for the process of establishing a level playing field for energy technologies.

¹¹ <http://externe.jrc.es>

Very few studies currently exist on future security risks due to fossil fuel dependency in the European Union (including securing delivery ways, political and military conflicts and so on). Such studies need to consider both the economic impact of the predicted security risks and the potential savings to be made from expanding renewable energy technologies to obviate these costs.

Various studies have been undertaken on the impact of wind electricity on the stability of energy prices. Research results are mainly available from Denmark, Spain and Germany, and are summarised below:

- According to the Spanish Wind Energy Association (AEE), the introduction of wind electricity into the Iberian market offsets the most expensive technologies and reduces its average load base power price¹²
- Several research projects have been completed in Germany¹³. The most comprehensive one comes from the German Ministry of the Environment (BMU, 2007a). According to this source, the merit-order effect caused a drop in the electricity price in 2006 worth €5 billion
- The large wind power production of west Denmark has been used by Morthorst¹⁴ to demonstrate that large amounts of wind power affect the spot power price. The higher the wind power production, the lower the spot power price in this area. The impact is much more pronounced during the day-time than during the night-time. Similar figures were found for other periods in 2005 and 2004

The above studies demonstrate the so-called 'merit-order effect', which means that introducing electricity from renewable energy systems causes power prices to decrease due to the displacement of (more expensive) conventional fossil fuels and that the net effect on the consumer – the difference between the additional cost of paying a mark-up for renewable electricity and the decrease of the electricity price due to introducing renewables – can be positive depending on the electricity mix and also the size of the country. This is more often the case when the energy mix includes older and more expensive traditional power stations.

The available studies conclude that wind energy has considerable positive effects on electricity prices. It would be useful, however, if further studies were conducted which considered more aspects and broader timeframes, so that conclusions can be drawn at European level. Currently, wind power plays a noticeable part in the generation mix of the Danish, German and Spanish markets, and in these countries, the theories mentioned above are illustrated. With growing wind markets in other countries such as France, Portugal, the United Kingdom, Italy, the Netherlands and Ireland, it will soon be possible to measure the influence of wind energy on energy markets on a broader scale. If such research

¹² In 2005, every time a new set of 1,000 MW was installed, the price fell by 0.19 €cent/kWh. In times of peak demand, the effect that 1,000 MWh have on the market is even higher, (about 0.5 €cent/kWh) (source: AEE)

¹³ Bode, S. (2006a): *On the impact of renewable energy support schemes on power prices*. HWWI Research, Paper 4-7 by the GWWI Research Programme. International Climate Policy, published by the Hamburg Institute of International Economics (HWWI). Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, BMU (2007): *Erfahrungsbericht 2007 zum Erneuerbare-Energien-Gesetz (EEG) gemäss § 20 EEG*

¹⁴ Morthorst, P.E. (2006): *The Impact of Wind power on the electricity price*

demonstrates that wind energy has a noticeable positive impact, it could be argued that the same benefits will be brought to the whole of the European Union.

E.3 Adapting the grid infrastructure

The Danish Transmission System Operators (TSOs) provide a good example of managing electricity demand in a system with a high penetration of wind energy. The Danish TSOs successfully handle 17% - 20% of electricity demand being provided by wind, and achieve a good balance of power due to the strong interconnection with Sweden and Norway.

Denmark also provides a positive example in terms of its reliable and quick authorisation procedure for grid developments that support offshore wind farms. Unlike many other countries, in Denmark it is the TSOs that arrange permits for offshore grid developments rather than the developer. This gives certainty to developers and reduces the time needed to develop a project. Where this is not the case (for example, in the UK), the process of obtaining permits for grid developments is time-consuming and risky.

The following research is being or has already been undertaken and can be built upon:

- EWEA's Tradewind project¹⁵: this project is investigating the development of market rules and interconnector allocation methods enabling a high wind power penetration in the EU power system. Recommendations are being formulated regarding the balancing, forecasting, market rules, allocation methods, siting and operation of wind power
- The European Wind Integration Study (EWIS) TSO project¹⁶ – this study aimed to set up a model for the integration of renewable energy sources on a large scale, and specifically considers wind power within Europe
- The IEA's Wind Power Integration into Electricity Systems project¹⁷, which investigates the issue of large-scale wind power penetration and provides guidelines for RD&D (similar to the current Strategic Research Agenda recommendations), policy recommendations and available research networks in 2005

F Optimising administrative procedures

Several EU directives are relevant to wind farm applications, including the Environmental Impact Assessment (EIA) Directive, the Water Directive, the Birds Directive and the Habitats Directive. These directives are common to all EU Member States, and yet their implementation in the spatial planning and permitting process varies significantly between Member States.

Within and between Member States there are substantial uncertainties and inconsistencies in the decisions taken on planning applications for wind farms. The decision criteria of the authorities responsible for the decisions differ considerably and are often only revealed at

¹⁵ <http://www.trade-wind.eu>

¹⁶ <http://www.wind-integration.eu>

¹⁷ OECD-IEA, 2005. *International energy technology collaboration and climate change. Case Study 5: Wind Power Integration into Electricity Systems*. Ref: COM/ENV/EPOC/IEA/SLT(2005)5

the end of the administration process, at which point a significant amount of time and money have been spent on planning applications.

As a result of the uncertainty in the permitting process, developers are adopting an inefficient approach to EIAs. For example, the scoping phase of an EIA should be used to define the content of the EIA with the administrative and environmental authorities. However when there is so much uncertainty in the process, developers are reluctant to 'scope out' issues, even if professional judgment deems them insignificant. As a result, much effort is unnecessarily put into issues of little relevance to the project in question.

The scoping stage of an application needs to be reinforced so that decisions are taken at an early stage on the impacts to focus on and so that developers can be assured that other issues will not be considered. The scoping process should be a process of intelligent, educated predictions based on experience and knowledge of environmental matters. The outcome of the scoping procedure should be a set of precise, well-founded issues that need special focus in the Environmental Statement, as well as alternatives to the proposed project and mitigating measures which ought to be considered by the developer.

More broadly, there is a strong need to review the EIA Directive in relation to administrative procedures. The European Commission has circulated guidance on the implementation of the EIAs¹⁸, yet despite this guidance, considerable variation remains in the EIAs undertaken in different Member States. Developers have reported that the administration of a similarly sized project can vary from one-two years to five-six years between Member States.

In the majority of cases, significant delays are introduced by long decision-making processes on planning applications. This is in part due to the citizens and planning authorities not really understanding Environmental Statements and having a lack of resources to help review them. It is proposed that the process be streamlined by establishing a central source of information and authority on the impacts of wind farms which can be accessed by developers and planners. It will also be important to ensure that guidance on appropriate timelines for various steps in the administration process is given to all Member States.

It is also important that areas are identified for large-scale wind farm developments, that in these areas developers can be confident that they will receive permits to develop, and that the permitting process will be streamlined. Once identified, these potential wind farm areas should be used as a basis for the long-term grid-infrastructure planning.

G Ensuring public support

There is often a discrepancy between the actual and the perceived level of public support. Politicians and decision-makers believe that wind energy is not widely accepted, although public opinion polls consistently show that it is. At a local level as a project is going through the consenting process, local decision-makers are often influenced by a vocal minority opposing the project and do not take an accurate gauge of overall public opinion, which is often favourable. There is a need to encourage the public to vocalise its support, that politicians get a clear and balanced message about true public opinion and that they themselves are well-informed about the issues relating to wind farm developments.

¹⁸ Implementation of Directive 2001/42 on the Assessment of the Effects of Certain Plans and Programmes on the Environment, European Commission, 2001

Opposition to wind energy is sometimes based on myths and inaccuracies about the impacts of wind turbines. Some issues require research in order to address concerns and provide robust answers (e.g. birds, bats, low-frequency noise, and house prices). Other issues need to be closed off as the research is complete and it is a matter of communicating the results effectively (e.g. intermittency and efficiency).

The benefits of wind energy are largely on a macro-scale (reductions in greenhouse gas emissions, conservation of finite resources, improvements in energy security) rather than a local scale, where new jobs and other economic benefits tend to be concentrated in the relatively short construction phase. Improving the tangible benefits that accrue directly to a local community around a proposed or existing wind farm would also improve public support. There are a variety of ways in which this can and does happen – for example community funds set up by the developer, local taxes, or direct investment by local people. The Renewable Energy Directive mentions benefits schemes, but these are just one of the options.

Full consultation with the public during the development phase of a wind farm is essential. Strategic planning, with public involvement at this early stage, would help facilitate this and increase the public's acceptance of the proposed schemes. Early involvement in the process can be beneficial, though it is not always possible or desirable from a commercial perspective. It is important that the consultation process is genuine, open and wide-ranging and conducted at a stage when aspects of the project design are still subject to change (as later changes can be costly). Consultation can be carried out in a variety of ways and experience has shown that road shows and exhibitions, where information can be presented in a constructive and non-confrontational way, are particularly effective. Good practice guidance on effective public consultation should be followed.

H RD&D funding

H.1 Funding for overall non-nuclear energy (NNE) research

In 2005, the European Commission's Advisory Group on Energy released a report¹⁹ which demonstrated the full extent of the reduction in European Union funding for energy R&D through its Framework Programmes.

Figure 6 demonstrates that energy research funding as a percentage of all EU R&D funding went down from 66% in FP1 to around 12% in FP6, and 7% in FP7.

Regarding FP6, the Strategic Working Group of the Advisory Group on Energy pointed out that:

"In face-value terms, expenditure is now less than it was 25 years ago, in real-value terms it is very much less and, as a percentage of the total Community R&D it is roughly six times smaller."²⁰

¹⁹ Source: SWOG, 2005. *Key Tasks for Future European Energy R&D: A first Set of Recommendations for Research and Development*

²⁰ *Key Tasks for Future European Energy R&D: A first Set of Recommendations for Research and Development by the Advisory Group on Energy: Directorate-General for Research Sustainable Energy Systems: EUR 21352, 2005*

The Advisory Group of Energy's Strategic Working Group (SWOG) called for the amount of funding dedicated to energy R&D to increase by a factor of four. It clearly expresses the energy challenges that the EU now faces:

"(SWOG) deplores the relentless erosion of energy R&D expenditure over the last 25 years. This has led to a level of funding which is neither commensurate with the importance and severity of the energy challenge nor with the conclusion that a wide range of technologies must be pursued to be sure that the challenge can be met."

"SWOG believes that, for the enlarged European Union (EU-25) the present level of EC energy R&D expenditure should be increased by at least a factor of four."

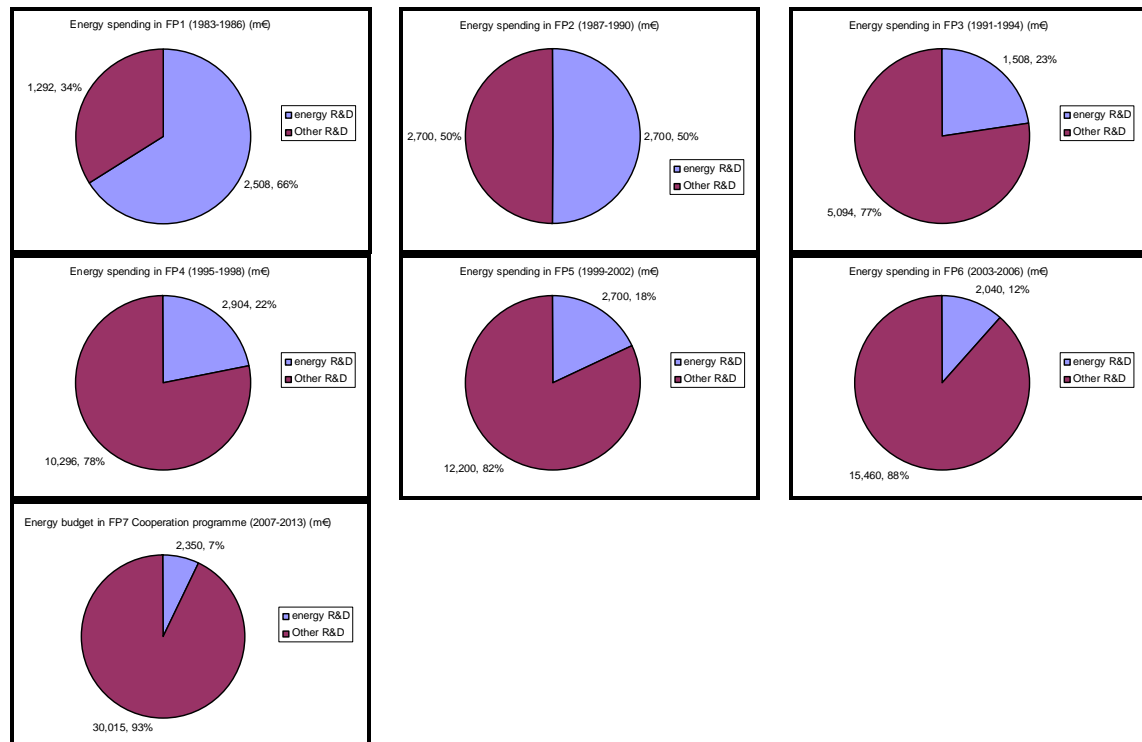


Figure 6: Energy spending through the seven Framework Programmes.

H.2 Funding for Renewable Energy Research

Under FP6, €810 million was dedicated to R&D under the "Sustainable Energy Systems" chapter.²¹ This represented a reduction of some 20% compared to FP5.

The name of the chapter or budget-line "Sustainable Energy Systems" gave rise to a lack of transparency in the way funding was allocated between technologies. The chapter included for example "clean coal" technologies, focusing mainly on the sequestration of CO₂. It also included hydrogen and fuel cells, which are not energy sources²².

²¹ €405 million to long-term R&D, administered by DG Research, and €405 million to short- to medium-term research, administered by DG TREN

²² Source: European Wind Energy Association, 2005. *Prioritising Wind Energy Research – Strategic Research Agenda of the Wind Energy Sector*

The status of the specific topic of R&D funding for renewable energy sources (RES) is cause for concern. EU funding for RES diminished slightly from €400–450 million in FP4 and FP5 to approximately €380–410 million in FP6. This trend does not reflect the current concerns regarding security of supply nor environmental issues.

For FP7, the aforementioned lack of transparency still remains. The €2.35-billion budget available for non-nuclear energy under the cooperation programme includes chapters such as:

- Hydrogen and fuel cells
- Renewable electricity generation (wind energy comes under this category, alongside photovoltaic, biomass, etc.)
- Renewable fuel production
- Renewables for heating and cooling
- CO₂ capture and storage technologies for zero-emission power generation
- Clean-coal technologies
- Smart-energy networks
- Energy efficiency and savings
- Knowledge for energy policy making

Detailed budgets are not available, neither is a time schedule for the calls for projects over the entire period covered by the Framework Programme. The respective renewable energy sectors are therefore not confident that they will obtain enough funding for the R&D projects needed in order to achieve the ambitious 20% binding target for energy production from renewables in 2020.

Moreover, 2020 is a tight deadline considering the industrial effort that needs to be made. Each renewable energy sector has to make a fast and strong technological deployment effort. A shared budget for these topics implies face-to-face competition between:

- Different renewable energy sources (RES)
- RES and “low-carbon” technologies
- RES and energy efficiency
- RES and smart-energy networks

This situation is paradoxical, as the EU objectives for RES development imply a strong and simultaneous effort in these areas which, far from competing, must cooperate. The recent Strategic Energy Technology Plan (SET-Plan)²³ proposes a set of instruments to solve this contradiction. Instruments and budgets are, however, yet to be defined.

²³ European Commission, 2007. COM(2007) 723 final. *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions – A European Strategic Energy Technology Plan (SET-Plan)*