Strategic Research Agenda / Market Deployment Strategy

(SRA/MDS)

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European Wind Energy Technology Platform

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The TPWind Secretariat would like to thank all those who contributed to drafting and producing this report. In particular, we wish to gratefully acknowledge the TPWind Working Group chairs and secretaries, the TPWind Steering Committee members and the TPWind Executive Committee members.

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Foreword

In 2013 the wind energy sector reached 117 GW of installed capacity in Europe, and would, in a normal wind year, produce 257 TWh of electricity, enough to cover 8% of the EU's electricity consumption.

Since 2006, the Wind Energy Technology Platform (TPWind), has been coordinating hundreds of wind energy professionals and researchers together with the European Commission to determine common R&D priorities for wind energy in order to efficiently target industry and public research funds.

To ensure that wind energy R&D funds are used efficiently, tackling the key technology issues, it is crucial that research resources across Europe are mobilised. This huge challenge will require coordinated investment between the EU, Member States and industry.

The launch in December 2013 of Horizon 2020[1], the new R&D research framework programme of the European Commission allocates €5.6 billion to non-nuclear energy R&D, with a specific commitment of €158 million and €169 million for renewables in 2014 and 2015 respectively.

This budget will help onshore wind energy to become competitive compared to conventional power generation by 2020 and offshore wind energy to become competitive by 2030.

Today, the wind energy sector and the EU's electricity system are facing new political, economic, technological, environmental and social challenges in parallel to the completion of the EU internal energy market and a new climate and energy framework for 2030. In this context, TPWind is updating the industry's R&D priorities seeking to ensure that wind energy continues to benefit Europe, grow cost-effectively, and becomes the backbone of Europe's electricity system.

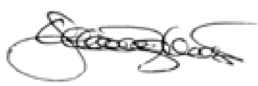
Through the European Wind Initiative[2] (EWI), set up under the Strategic Energy Technology Plan[3] framework, TPWind together with the European Commission, Member States and the European Energy Research Alliance ensures funding for wind energy R&D is in line with the Strategic Research Agenda (SRA). For the 2010-2020 period, the EWI has a budget of €6 billion (bn), more than half of which will be provided by the wind energy industry. This budget should be used to:

- Maintain Europe's technology leadership in onshore and offshore wind power;
- Make onshore wind the most competitive energy source by 2020, with offshore following by 2030;
- Achieve a 20% share of wind energy in EU total electricity consumption by 2020;
- Create 250,000 new skilled jobs in the EU by 2020.

TPWind also collaborates with the European Electricity Grid Initiative[4] (EEGI) to ensure a transformation and optimisation of the whole power system to integrate a high share of wind power and other renewables.

Moreover, a number of cross-sectoral R&D issues have been discussed with the TPWind Advisory Board and included in the work of this SRA. Cross-sectoral collaboration is fundamental to avoid fragmentation in the R&D sector, and I would like to thank the members of the TPWind Advisory Board for their collaboration.

Finally, I wish to thank and congratulate each TPWind member for the high-quality exchanges and hard work that have taken and continue to take place within TPWind.



Henning Kruse
TPWind Chairman

1 http://ec.europa.eu/programmes/horizon2020/en/
2 http://setis.ec.europa.eu/implementation/technology-roadmap/european-industrial-initiative-on-wind-energy-1
3 http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm
4 The grid operators' 2010-2020 R&D Programme, part of the EU Strategic Energy Technology Plan http://www.gridplus.eu/eegi

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1 EXECUTIVE SUMMARY

In 2008, TPWind published the first ever Strategic Research Agenda and Market Deployment Strategy (SRA/MDS) to identify the sector's research priorities and set out a vision for wind energy's share in the EU's electricity mix. The key goal was to significantly reduce the cost of wind energy and to reach 12%-14% of the EU's electricity consumption by 2020 and 25% by 2030.

Since then, wind energy has risen from 4% share of EU consumption to 8% today, and is expected to more than triple by 2030. This remarkable performance has been made possible thanks to the industry's significant R&D efforts, the involvement of the research community and the decisive political support, both at national and European level. Indeed, over the past years, the wind industry has committed more than twice as much of its revenue to research than the EU average[5]. The adoption of the binding 2020 renewable energy targets, the launch of the Strategic Energy Technology Plan (SET-Plan) and the European Wind Initiative, together with the FP7 programme to fund renewable energies, have played a significant role.

Wind energy is developing rapidly around the world and the industry's supply chains are becoming global. The European wind energy industry is still a world leader and has a substantial first mover advantage. The wind industry has improved EU trade flows with a positive trade balance for wind turbine components alone of €2.45 billion (bn) in 2012[6]. In the same year, European companies held 55% of global wind energy patent applications, compared to the EU industry overall share of 32.5%[7].

Moreover, the European wind industry represents a growing number of jobs. In 2011, the European wind industry employed 270,000 people and this could increase up to 675,000 by 2020[8] according to the European Commission.

5 EWEA report Green growth (2012), http://www.ewea.org/fileadmin/files/library/publications/reports/Green_Growth.pdf
6 Commission staff working document, Energy economic developments in Europe, January 2014, http://ec.europa.eu/economy_finance/publications/european_economy/2014/pdf/ee1_en.pdf
7 Ibid.
8 Calculations based on Green Growth, EWEA (2012) and Energy economic developments in Europe, January 2014.

For Europe to keep its first mover advantage, and leadership of the global wind power industry, the EU needs to maintain its R&D momentum in support of its wind industry, both onshore and offshore. Therefore EU research and innovation policy should aim at implementing the SET- Plan and prolonging it post-2020, and concentrating its scarce public funding resources on key energy technologies, such as wind.

Reaching the ambitious goals set by the European Wind Initiative[9], to make onshore wind energy the most competitive energy source by 2020 and offshore wind energy by 2030, requires significant investments in R&D. For the 2010-2020 period the European Wind Initiative requires €6 bn. Within this budget, €3.1 bn should come from private investors, €1.86 bn from the EU budget and €1 bn from national programmes.

If these R&D engagements are met, together with the volume targets, TP Wind estimates that the levelised cost of energy[10] can be reduced up to 50% for offshore wind energy and up to 20% for onshore compared to 2008 over the next 20 years.

1.1 External conditions: climate, waves and soil

One of the most important drivers for reducing the cost of energy is minimising uncertainty and improving the predictability and availability of wind energy. Key to this is establishing models and data that accurately describe the environmental conditions in which wind turbines operate. By integrating environmental information in all phases of the life cycle of a wind power plant, wind turbine design can be optimised. This reduces risks related to siting, optimises layouts reducing the impacts of loads, maximises production and enables the integration of wind power into the electricity grid based on advanced forecasting.

Reducing uncertainty alone will significantly improve wind energy projects' profitability and financing conditions as less equity will be required. Depending on the loan structure, up to 6.5% improved Internal Rate of Return (IRR), together with a reduced equity, can be achieved.

At the same time, standardisation of wind resource assessment will increase investors' confidence by minimising risks through more accurate energy predictions and less uncertainty. This will help maintain the security of the energy supply.

To achieve this, TPWind suggests concentrating on five areas:

1. The development of new measurement techniques to capture all relevant design parameters for wind turbine design and siting;
2. Cost-optimisation of wind turbine design by further developing in-depth knowledge of various external wind conditions (wind, ice…);
3. Cost-optimisation of wind farm siting and design by improving methods for atmospheric and wind farm modelling;
4. Cost-optimisation of electricity system operation through improved wind power forecasting methods;
5. Standardisation to ensure that research and new information is transferred efficiently to the market.

1.2 Wind turbine systems

The wind turbine is the most significant element in the cost of energy from wind farms. It can represent up to 80% of onshore wind power plant project costs and up to 50% for offshore projects.

To achieve reductions in LCOE, TPWind recommends the following priorities classified according to their scientific and technical disciplines:

1. **Wind turbine as a flow device** – the increase in size and complexity of wind turbines demands better understanding of aerodynamic phenomena in order to achieve optimal designs. Developing model and simulation tools that take into account all relevant interactions of wind flow phenomena with very large wind turbines is needed. The challenge is to combine these interactions with fast and accurate calculations and more efficient verification methods, taking into account also extreme events like icing. This will enable development of larger, optimised and more advanced wind turbine designs (in particular offshore) with improved aerodynamic capacity factor.

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[9] http://setis.ec.europa.eu/implementation/technology-roadmap/european-industrial-initiative-on-wind-energy-1

[10] The levelised cost of energy is defined as the actualised KWh cost over the whole project lifetime, taking into account the actualised value of all components. The costs include all development capital, operating and decommissioning costs incurred by the wind farm owner/developer over the lifetime of the project.

2. **Wind turbine as mechanical structures/materials** – optimisation of construction materials and improvements in structural integrity can be achieved by further increasing knowledge on design loads for wind turbine components, better characterisation of material properties and their relation with manufacturing processes, developing methods for verification of design loads and structural strength, reliability of components and for extending lifetime of wind turbine systems and finally, by developing new more cost-efficient materials with improved properties such as composites. All of this will increase reliability of wind turbine components while reducing the amount of materials used during design and manufacturing processes without compromising safety.

3. **Wind turbine as a grid connected electricity plant** – the reliability, efficiency and cost of wind turbine's electric conversion system need to be further improved. To this end, research is needed in developing high voltage electronics for wind farms, enhancing power converters to maximise their efficiency and enable grid support services, developing new, lightweight, low speed, low maintenance generators with alternative materials to rare earths (for permanent magnet types) and to extend design standards to include grid code requirements internationally.

4. **Wind turbine as a control system** – optimisation between wind turbine performance, noise emission, mechanical loading and components lifetime needs to be further integrated into wind turbine operational control strategies. This includes power output optimisation and control strategies for grid support services provision, controlling loads during extreme weather events, developing algorithms to further optimise aero-elastic stability of wind turbines and the development of integrated control systems able to incorporate predicted wind flow conditions, condition monitoring and O&M procedures.

5. **Innovative concepts along the value chain and integrated design** – research in highly innovative wind turbine and component concepts, including substructures is needed. This requires improved design tools with more advanced probabilistic methods able to incorporate the risks involved in changing the fundamentals of wind turbine design together with support schemes for risk sharing when developing such radical designs. Priorities include developing advanced rotor designs for very large offshore wind turbines, innovative wind turbine design concepts with fewer components, simulation models for testing new designs, input failure mode analyses into machine safety and reliability design and flexible manufacturing methods allowing tailored blades production.

6. **Operation and maintenance (O&M)** – O&M strategies need to be improved by gradually replacing corrective maintenance with preventive and condition based monitoring. This becomes more urgent when wind turbines are more complex and more difficult to access, like offshore, mountainous areas and icing climates. In particular this applies to future deep water floating wind turbine systems. Research priorities include integration of condition monitoring and fault prediction capabilities into wind turbine control systems, sensors development and analytical tools to determine remaining lifetime of components, development of methods for easy verification, access and replacement of components in difficult to access sites and development of dedicated access technologies for remote places and extreme weather conditions.

7. **Standards and certification** – design and testing standards need continuous improvements and to be based on extensive research and state of the art methods and technology. Also, a better alignment of different technology certifications and quality systems is needed. Standards and certifications priorities should be geared to wind turbine issues with high cost impact such as loads, control systems, blades, towers, foundations and electrical and mechanical transmission components.

1.3 Grid integration

For wind energy to become a mainstream power generating source, new methods of planning and operating the grid with high shares of wind power are needed. TPWind suggests that grid integration research focus on three main areas:

1. **Wind power capabilities for ancillary services provision** – ensure enhanced wind power capabilities are developed for individual turbines, wind farms and clusters of wind farms including design tools and models; testing and verification methods not only for frequency and voltage capabilities but also for new advanced capabilities included in grid codes and standards; and finally harmonisation, standardisation and interoperability of methods and technologies for ancillary services provided by wind power.

2. **Grid connection, transmission and operation** – the way wind power is connected to the grid and the way the grid is operated and managed when there are high shares of wind power will have to change. In cooperation with the European Electricity Grid Initiative (EEGI), the wind sector should develop technologies to provide adequate network transmission capacity in the existing and future network and optimise the use of wind power in the power system. Methods and tools to support the secure operation of power systems with large-scale wind power need to be further developed. New concepts for grid connection and transmission of wind power should be also explored. Finally, improvement methods and tools for modelling, testing and validating the electrical characteristics of wind power.

3. **Wind energy in grid management and power markets** – the wind sector needs to develop detailed generation, transmission and demand scenarios. Assess the impact of high wind energy penetration on power system planning and operations and the adequacy of generation capacity with new and

improved tools. Investigate new market designs and business models, including how it can most efficiently be linked to other energy markets like heat, gas or transport fuels.

Improved portfolio and asset management tools for a high penetration of renewables are required, taking new business models for all generators into account. Finally, there is a need for assessing and demonstrating economic benefits of providing ancillary services and power balancing in higher wind penetration scenarios and improve probabilistic generation, demand and price forecasting and use of such forecasts for power system management and market integration.

1.4 Offshore technology

The most critical priority for offshore wind power is to significantly lower its cost of energy in order to become competitive with conventional power generation by 2030. This requires large scale infrastructure for research, development and demonstration, not only for wind turbine structures, but also for the complete life cycle of a wind energy project. This includes design, manufacturing, transportation, logistics, construction, operation, maintenance and decommissioning. An integrated design approach that can minimise the LCOE is targeted by including the site specific boundary conditions in the wind turbine design.

TPWind suggests prioritising six research topics for offshore wind technology development:

1. **Sub-structures** – the development of innovative fixed-bottom and floating sub-structure designs, the improvement of manufacturing facilities and processes applying the latest technologies, the development of methods to extend the operations and lifetime of the turbines, improving the repowering options.

2. **Logistics, assembly and decommissioning** – achieving cost reductions through new logistics and installation methods, infrastructure and products.

3. **Electrical infrastructure** – developing innovative wind farm collection grids for offshore applications, optimising the offshore grid infrastructure and improving system services from offshore wind farms.

4. **Wind turbines** – conducting R&D to achieve large scale commercialisation of 10 MW range turbines.

5. **Operation and maintenance** – Investigate versatile service fleets and safe access, improve reliability and availability and research on full cycle cost models for optimisation of asset management.

6. **External conditions** – research on soil conditions, meteorological and ocean (Met-Ocean) conditions, spatial planning and interactions with environmental factors of offshore wind energy.

1.5 Market deployment strategy

Onshore wind energy has been developed in record time, taking a growing share in the energy mix. Offshore wind has taken its first steps in the energy market, and in view of the success of onshore wind, a bright future seems to lay ahead. However, the current design of electricity markets does not enable optimal integration of large shares of renewables into the power grid.

Hence, TPWind recommends six topics necessary to enhance the market deployment of wind energy:

1. **Enabling market deployment** – a level-playing field in the evaluation of different power generation technologies is required. There is a lack of coordination and holistic perspective taking all costs and effects into account when evaluating wind power generation versus other generation technologies.

   Policy measures driving faster European energy market integration are needed to facilitate wind power deployment and its integration to the market. This needs to be supported by measures such as grid reinforcement, interconnection expansion and improved operational routines from transmission system operators (TSOs); market coupling, well-functioning intra-day cross-border trading and most importantly development of market rules promoting flexibility and a broad range of ancillary services in a market-based framework to accommodate higher shares of wind power.

Similarly, improved financing conditions for wind energy projects, especially reducing the cost of capital for offshore wind are urgently needed. Several challenges need to be tackled in this sense such as the extrapolation of onshore asset performance data to offshore environments and all the associated uncertainties, the availability of performance data for offshore wind assets that allow key performance indicators to be shared with the finance sector, the level of risk – perceived and real - from investors, the lack of consistency in energy policies across the EU regarding offshore wind connection, harmonisation of grid codes and optimisation of Operation and Maintenance (O&M).

2. **Adapting policies** – wind energy requires stable and long term market and regulatory frameworks. 2030 renewable energy targets are key to providing such frameworks. National frameworks should take account of Member States individual circumstances and wind power potential, establishing targets for each energy technology and maximising regional economic benefits by relying on local sources of energy, as long they are competitive in price/cost terms.

3. **Optimising administrative procedures** – encourage Member States (MS) to produce binding long term strategic plans for developing onshore and offshore wind farms and ancillary services, establish a one-stop-shop for MS to provide guidance on consenting procedures for marine spatial planning following the latest benchmarking of the sector as defined in EU draft 2013/0074 and facilitate the development of offshore wind projects in which more than one MS is involved.

4. **Integrating wind to the natural environment** – further research is needed into potential effects on birds and bats, effects of underwater noise from piling of foundations on marine mammals and fish, cumulative effects, including population – or ecosystem-level impacts of wind farms, social acceptance of wind energy and potential effects of wind farms on radar and aviation regulation.

5. **Ensuring public acceptance of wind power** – review existing concerns on wind energy and identify where further research is needed. Investigate motivations behind public opinion and people's concerns on wind farm projects, review case studies, looking at local opinion before and after the installation of wind farms. Misinformation should be addressed based on solid scientific studies. Review the range of mechanisms used across Europe for transforming global benefits into tangible benefits for local communities and identify how these can affect public opinion. Review current best practice on effective consultation processes and local stakeholder management and the manner in which information is disseminated, review case studies to identify and promote examples of positive effects of wind energy developments in different contexts, to clearly show benefits at local level, Increased focus on understanding the mechanisms behind social acceptance of wind energy in the offshore environment, assessment of what factors are important for social acceptance in the context of repowering.

6. **Human resources** – quantify the need and level of O&M education in the EU and accession countries at national level and elaborate solutions for "skill and resource drain" towards high salary sectors like oil and gas, such as compensation schemes based on career development, review current wind energy masters programmes and encourage the creation of new programmes, involving different European universities and quantify offshore related skills aligned with installation roadmap.

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2 INTRODUCTION

2.1 The European Wind Energy Technology Platform (TPWind)

During the Barcelona European Council in 2002[11], the European Union (EU) set the goal of increasing its research effort to 3% of the EU's GDP by 2010, with two-thirds coming from private investment and one-third from the public sector. To reach this objective, the European Commission proposed six key instruments[12], one of which is the implementation of Technology Platforms.

Technology Platforms bring together companies, research institutions, investors and regulatory authorities at European level to define a common agenda aimed at mobilising national and European public and private resources for research and development (R&D). With the support and guidance of the European Commission, Technology Platforms work to achieve optimum research results in their sector and to reflect wider community interests.

TPWind is the European Technology Platform dedicated to the wind power industry. It develops on policy and technology research and development pathways for the wind energy sector. TPWind facilitates the development of effective, complementary national and EU policy to build markets as well as a collaborative strategy for technology development. Its ultimate aim is to achieve cost reductions to ensure the full competitiveness of wind power, both onshore and offshore.

TPWind is composed of stakeholders from industry, government, civil society, R&D institutions, finance, organisations and the wider power sector, at both Member State and EU level. It is the only body with sufficient representation or "critical mass" of wind-specific knowledge and experience to be able to fully understand and map realistic and prioritised pathways for policy and technology R&D, taking into account the full range of sector needs.

11 European Presidency, 2002. SN 100/1/02 REV1, "Presidency Conclusions – Barcelona European Council 15 and 16 March 2002."

12 European Commission, 2004, COM(2004) 353 final, "Communication from the Commission - Science and technology, the key to Europe's future - Guidelines for future European Union policy to support research."

TPWind was officially launched in October 2006, in the presence of EU Energy Commissioner Andris Piebalgs and has been financed by two EU-funded projects, WindSec (6th Framework programme) and TOPWind (7th Framework programme).

This Strategic Research Agenda (SRA) is the main deliverable of TPWind. It sets out research and technological development priorities for the medium to long term, including measures for enhancing networking and clustering of the Research, Technology and Development (RTD) capacity and resources in Europe for the wind energy sector. It also makes an important contribution to the preparation of the Commission's proposals for future research programmes.

In parallel with this SRA, TPWind works on a Market Deployment Strategy (MDS) which anticipates the key elements for the effective implementation of the SRA. It aims to bridge the gap between the current state of development of a given technology and its deployment.

The implementation of the SRA involves support from a range of sources, including the European Commission's Framework Programmes, other sources of European funding, national research programmes, industry funding and third-party private finance.

2.2 TPWind objectives

The objective of TPWind is to identify areas for increased innovation, new and existing research and development tasks. These will then be prioritised on the basis of "must haves" versus "nice to haves," the primary objective being overall (social, environmental and technological) cost reductions. This will help to achieve EU objectives in terms of renewable electricity production.

The Platform develops coherent recommendations, detailing specific tasks, approaches, participants and the necessary infrastructure, in the context of private R&D, as well as EU and Member State Programmes, such as Horizon 2020. TPWind also assesses the overall funding available to carry out this work, from public and private sources.

Through its SRA, TPWind encourages Member States, EU institutions and the wind industry to intensify their research efforts in line with, or exceeding, the overall Lisbon objectives, while increasing its focus on the long-term view. TPWind will encourage long-term research findings to be considered when new wind energy prototypes are developed.

Through the Market Deployment Strategy, Member States, EU institutions and the wind industry are able to modify policy developments to the changing needs of the technology as it matures.

Accordingly, TPWind is structured as follows:

- Technology Research and Development Working Groups responsible for building the Strategic Research Agenda
- Policy/Market Development Working Group responsible for building the Market Development Strategy

Additional information on TPWind can be found at: www.windplatform.eu.

2.3 Strategic research agenda: structure

The SRA is divided into four research priorities aimed at reducing the social, environmental and technological costs of wind energy. The priorities are:

- External conditions: climate, waves, and soil
- Wind turbine systems
- Grid integration
- Offshore technology

For each topic, short, medium and long-term research priorities are defined and actions are identified, to meet these priorities. Targets are given in the different chapters: we recommend handling these indicators carefully, since they are based on long-term forecasts and might change in the upcoming years.

Some of the thematic priorities are addressed in more than one chapter. The table below illustrates where the main thematic priorities are taken into analyses.

TABLE 1 SRA RESEARCH PRIORITIES

Research priorities	External conditions, climate, waves, and soil	Wind turbine systems	Grid integration	Offshore technology	Market deploy-ment strategy
Measurement systems	x			x	
Interaction climate-wind turbines	x				
Multi-scale modelling	x				
Wakes	x			x	
Forecasting	x		x		
Condition monitoring	x			x	
Standardization	x			x	x
Wind turbine as a flow device	x	x		x	
Wind turbine as a mechanical structure/materials		x		x	
Wind turbine as a grid connected electricity plant		x		x	
Wind turbine as a control system	x	x	x	x	
Concepts and integration		x			
Operation and maintenance	x	x		x	x
Standards	x	x			x
Wind power capabilities for ancillary services provision			x		x
Grid connection, transmission and operation	x		x		x
Wind energy in grid management and power markets			x	x	x
Sub-structures				x	
Logistics, assembly and decommissioning	x			x	x
Electrical infrastructure			x	x	x
Wind turbines and farms	x			x	
Operations and maintenance	x			x	x
External conditions	x			x	
Safety, environment, and education	x				
Enabling market deployment					x
Adapting policies					x
Optimising administrative procedures					
Integrating wind to the natural environment	x				x
Ensuring public acceptance to wind power					x
Human resources					x

In order to meet the primary objective of the Platform, a stable and well-defined market and favourable regulatory framework is needed. The Market Deployment Strategy is looking at the thematic priorities related to this.

3 EXTERNAL CONDITIONS: CLIMATE, WAVES AND SOIL

2030 Objectives

The target is to reduce the cost of wind power throughout the life cycle of a wind farm. The design, siting and operation of the wind turbines in the electrical grid can be optimised through the integration of accurate models and data describing environmental conditions. This would reduce financial risks. By combining these actions, a significant reduction in the LCOE can be achieved. If the internal rate of return (IRR) improves and debt capacity is increased, project costs could be further reduced. The average levelised cost of offshore wind energy can be reduced up to 50% in the next 20 years. Onshore the cost reductions are smaller but could be as high as 20%.

Consequently, TPWind proposes to improve the efficiency and accuracy of wind design conditions, wind siting, wind resource assessment and forecasting. This research will contribute to improve:

- Wind turbine design: cost-optimised design of wind turbines with in-depth knowledge of wind loads;
- Siting of wind farms: offshore – including coastal areas – and onshore, also at icing climates;
- Improved standards and software for wind resource prediction and site assessment, including uncertainty evaluation, coupling both atmosphere-ocean and sea-land interactions[13];
- Grid operation: power system management and maximum wind power penetration can be enhanced by improving short-term power production forecasting.

The three main stages of a wind project life cycle – design, siting and operation (See Fig. 1) – are strengthened by six research topics:

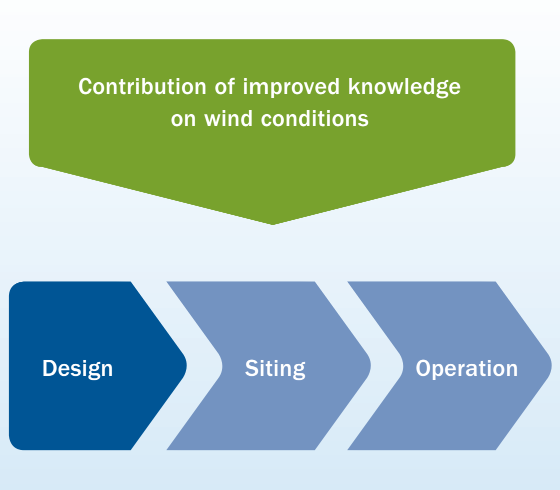
1. Measurement systems focused on ground- and satellite based remote sensing;
2. Interaction of climatic conditions with wind turbines;
3. Multi-scale modelling chain (including long term correction);
4. Wakes: single, multiple and far wakes;
5. Forecasting focused on short term prediction;
6. Condition dependent construction, operation and monitoring.

[13] Although offshore siting is of particular interest due to the generally higher wind resource compared to onshore, the cost of energy also dramatically decreases by improving annual energy production (AEP) estimates onshore, particularly over mountainous and forested sites, where the wind and flow models are less accurate and where siting becomes a much more.

The first research topic – measurement systems – will be addressed in section 3.1. The other topics are covered in sections 3.2, 3.3 and 3.4, dedicated to the three different stages of a wind project life cycle.

Finally, the chapter looks at standardisation (from turbines to measurements, (section 3.5), which should be included in R&D programmes to ensure efficient transfer of knowledge between the research community and the market.

FIGURE 1 CONTRIBUTION OF EXTERNAL CONDITIONS TO THE REDUCTION OF LCOE



Source: TPWind

The topics identified above are fundamental for the description of wind resources, the improved knowledge of design conditions and the forecasting of wind power. Consequently, they are the basis for the effective integration of wind energy into the power system. They are also the basis for improving the other four main R&D areas covered by TPWind: wind power systems, grid integration, offshore, and policy issues (such as spatial planning, environmental impact, social acceptance and market conditions). The improvement of standards, models and software requires planning experimental campaigns for validation, which should be extended to offshore, mountainous, and forested areas, as well as to regions with extreme weather conditions. Methods for uncertainty evaluations for cold climates need to be significantly improved.

Further standardisation, evaluation and dissemination of technologies for wind measurements, such as remote sensing (i.e. wind lidars and radars) and for wind modelling, such as computational fluid dynamics (CFD) methods, are needed. An effective and standardised evaluation of uncertainty within each stage of the life cycle of a wind project is a priority. Cost competiveness of wind energy is closely linked to accurately quantifying uncertainty. It has an impact on the cost of finance and is therefore as important as the Annual Energy Production (AEP) estimates.

By 2030, the wind energy industry in Europe is expected to use accurate, fast and dynamic wind atlas[14] calculations in a variety of climatic conditions and for difficult to access sites, particularly offshore, at coastal sites and over mountainous and forested areas. Such calculations will be validated against a set of experiments where remote sensing, traditional anemometry, and CFD efforts will be combined. The calculations will also include uncertainty estimation as well as turbulence and extreme conditions statistics. These will also provide a basis for the effective and optimal design of wind turbines. Hence, future turbines and wind power plants will be site-optimised for further reductions in LCOE.

A model chain[15], in which several models are coupled and interact to solve and capture the different temporal and spatial scales, should be improved. An interface allowing users to access results at different stages, from climatic to turbulence scales and benchmark them against locally observed data is needed. Part of the work required is related to:

- Long term wind resource correction, which is one of the largest sources of uncertainty[16] in wind energy projects. New generation of global and regional (meso-scale) reanalysis derived products is to be developed and used in combination with long term observational datasets to reduce uncertainty;

[14] A wind atlas is a set of parameters describing the wind characteristics of an area (a few to tens of kilometres), which can be compared to other areas for the large-scale placement of wind turbines.

[15] Model chain here refers to the way in which different datasets are connected to different model types (ranging from global atmospheric to turbulence models) in order to perform wind resource assessment. This is also known as the dynamics of the wind atlas.

[16] In numerical weather prediction, a reanalysis is a dataset representing the evolution of the state of the atmosphere over an extended period of time by integrating observations and a numerical model. It can be global if the model used is of this kind, and regional or meso-scale when generated with a limited area model.

- Accurate quantification of external conditions in very complex terrain[17] and extreme conditions;
- Accurate description of wakes to reduce loads, increase production both within a wind farm and between large clusters;
- Coupling between atmospheric and ocean models, as well as experimental studies on the sea-land interaction for offshore and coastal deployment;
- Improvement of numerical weather prediction (NWP) models for short term prediction of wind power;
- Measurements and modelling of wind characteristics above hub height (>100m) for large scale wind turbines (>6 MW).

3.1 Measurement systems

3.1.1 Objectives

Conventional measurement systems are reaching their limits as they can no longer cost-efficiently cover the full rotor disk of large scale wind turbines with tip heights above 200m. As a consequence, new measurement systems are required to capture flow parameters across larger areas at affordable costs. Such measurements are necessary, as the common models for wind prediction are valid for the first tens of meters above ground only. High above the ground, reality can substantially deviate from theory. This can have consequences for turbine design – as structural loads might be different from expected – and for siting, as either the wrong turbine type is placed on a site and/or the performance deviates from the expected production.

TPWind's first priority in wind metrology is therefore to accelerate the development of new measurement techniques that capture accurately all relevant design parameters for wind turbine design and siting. These parameters include wind speed, temperature, gusts, directional changes, turbulence, shear and flow tilt as well as thermal stratification. For offshore conditions they have to be supplemented by oceanographic measurements capturing waves, sea surface temperature, currents and salinity of water.

The new measurement technologies form the basis for a number of model validations for flow modelling as well as wake modelling, contributing to reducing uncertainties in energy yield predictions and thus reducing the LCOE. Particularly for offshore, new technologies like remote sensing will develop as an alternative to expensive meteorological masts. Through the improved understanding of external conditions combined with load measurements, these technologies are also key for leaner wind turbine design. Finally, new measurement techniques that capture the turbulent and complex flow in front of large turbines will enable load-optimised control systems, which, again, are one cornerstone of lean turbine design. Nevertheless, in-situ measurements of turbulent fluxes remain necessary as well as tall meteorological masts. Icing climates need improved measurement techniques to reduce the uncertainties, both for measuring wind and icing events.

A rigorous roadmap and testing of any new measurement technology is to be established to accelerate their maturity and would be the basis for achieving bankability.

For onshore conditions the uncertainties can be reduced in the order of 4% of the AEP. Such a reduction would not be cost effective with traditional measurement systems, as observations above 200m might be required. The reduction of uncertainty can be translated into a 1.75% improved IRR and up to 20% reduced investment volume from the owners' side.

For offshore conditions, the uncertainty can be reduced in the order of 1% of the AEP. However, the investment costs for an offshore measurement campaign can be reduced by a potential 75% as per today's pricing. The development of measurement methods adapted to the offshore environment is therefore of particular importance.

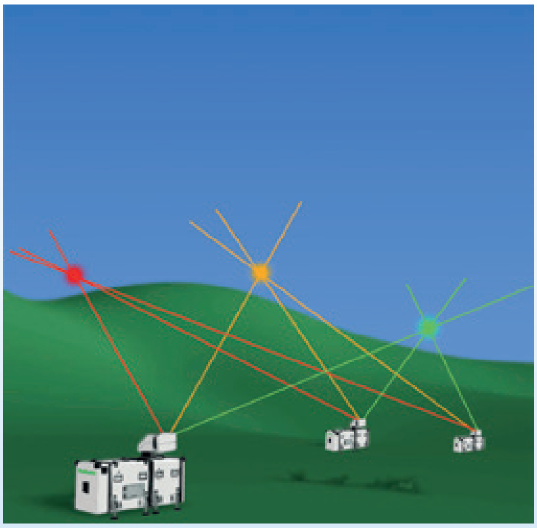
3.1.2 Research priorities

- Development and validation of advanced cost-effective sensing technologies capturing relevant atmospheric parameters for wind turbine design and siting including turbulence, and other extreme external conditions both for onshore and offshore deployment from fixed and floating platforms for heights exceeding 200m (see Fig. 2);
- Development of new stand-alone technologies for measuring offshore oceanographic parameters including waves and currents capable of operating for long periods in harsh offshore conditions;

[17] In wind resource assessment, the terrain inducing changes in the wind field in short-length scales, such as coastal areas, very hilly and mountainous terrain or diverse forest is referred to as complex terrain.

- Development and validation of advanced sensing technologies directly coupled to the wind turbine's control systems for load mitigation and performance improvement;
- Development and validation of satellite based remote sensing techniques for wind measurements offshore, promoting services and adapting sensors to the needs of the wind industry;
- Development of advanced acoustic imaging for improved understanding of noise generation and propagation;
- Development of a roadmap for evaluation of new measurement technologies including calibration procedures and assessment of uncertainties, aiming for an accelerated maturing and consequently acceptance of new technologies;
- Development and validation of cost-efficient cold climate measurement technologies.

FIGURE 2 3D SCANNING OF A POTENTIAL WIND PROJECT SITE USING ADVANCED SENSING TECHNOLOGIES



Source: DTU Wind Energy

3.1.3 Impact

New cost-efficient and accurate measurement technologies will facilitate a range of different measures to reduce uncertainties and thus the LCOE:

- Wind turbine design will become leaner through the improved knowledge of atmospheric conditions, which in turn makes it possible to reduce safety factors and consequently reduce turbine pricing;
- Load mitigation through intelligent control systems coupled with remote sensing will contribute to cost optimisation of wind turbine design;
- The advanced measurement technologies will be the basis for the validation of the new generation flow and wake models, which are the foundation to the 3% cost reduction vision;
- Reduced uncertainties in the AEP will directly impact the cost of financing and reduce the LCOE;
- Project planning will benefit from reduced investment costs, particularly offshore. Planning operation and maintenance (O&M) for offshore interventions requiring data such as wind, waves, etc. will benefit;
- Thorough testing using a defined roadmap will create acceptance throughout the industry for any future technology;
- The new measurement technologies will also contribute to improvement in other areas such as meteorology and forecasting.

3.2 Design of wind turbines (design conditions)

Developing cost-effective and reliable large scale turbines can greatly contribute to the achievement of the EU's targets in terms of renewable energy production and reduction of greenhouse gases. The structural design of very large wind turbines and the expected high wind energy penetration requires improved operational design requirements.

Turbines are often operating under unforeseen and not always well understood wind inflow conditions, which lead to non-optimal power production and uncertainty over structural loads. Traditionally, for load calculations during the design process, only a limited set of design parameters are taken into account to characterise the complex inflow on the rotor during the turbine's lifetime. In the offshore environment, the complexity increases due to the combined wind-wave effects over turbines. Currently, this simplification is overcome by increased safety factors and a robust design.

For cost-effective design a more detailed knowledge of design conditions becomes a key to success. The following research topics have been identified as clearly influencing knowledge on design conditions:

- Measurement systems (see section 3.1)
- Interaction of climatic conditions and wind turbine

3.2.1 Interaction of climatic conditions and wind turbine

3.2.1.1 Objectives

Together with new sensing technology and new methods for modelling climatic conditions and their interaction with the large-scale wind turbines, the main objective of this research is to enable a lean and thus cost-optimised design of wind turbines.

The specific objectives are:

- Improved modelling of the turbine inflow conditions (free atmosphere);
- Improved modelling of the wind/wave interaction for offshore applications;
- Improved modelling of downstream conditions for single and multiple wake situations;
- Coupling wind turbine models with improved atmospheric and ocean models for a better understanding of loads and performance of wind turbines both, stand-alone and in wake situations inside and between wind farms.

3.2.1.2 Research priorities

- Establishment of methods to determine climatic design conditions through improvement of Numeric Weather Prediction – NWP – models and other meteorological models (meso- and micro-scale, large-eddy simulation - LES, etc.), including new surface-layer models and fully integrated wind/wave/current coupling and interaction models for offshore conditions;
- Collection and analysis of single and multiple wake observations, including load measurements and wind turbine state (particularly offshore). This analysis will be enabled by the development of new sensing technologies;
- Wake propagation models through improved understanding of the interaction between wakes and the terrain/water;
- Modelling of wake-induced loading response of the wind turbine;
- Investigating the performance of turbines when design conditions are not 'standard', e.g. under high/low shear, high/low turbulence, high vertical inflow angle and high wind turning;
- Investigate the acoustic response of the turbine under different wind conditions, e.g. under variable wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity and inflow angle conditions. Mitigation strategies should also be developed;
- Development and validation of design tools for optimisation of wind farms.

3.2.1.3 Impact

The ability to properly predict climatic conditions, along with the reduction of their statistical uncertainty, will substantially contribute to the cost-effective design of large-scale turbines as better understanding of wind inflow and wakes impacts the turbine loads and production. As a consequence, a new leaner generation of wind turbines can be designed with an optimum balance between performance and loading for stand-alone purposes as well as in wake situations. At the same time the acceptance of wind energy will be increased through noise optimisation.

The reduction of uncertainties - the core of this research topic - will lead to optimal design of the rotor, tower and foundation. The safety factors can reduce the cost of energy by prescribing lower safety margins, because they are now calibrated with validated load models. Current safety factors do not include such validations for future turbine sizes. The improvements can lead to more price-competitive turbine designs which may improve the competitiveness of EU exports.

The benefits are manifold. Reduced uncertainties will be coupled with reduced safety design margins which in turn will reduce wind turbine pricing. Life times could be extended by the new knowledge of the interaction between wind turbine and the wind, wind/waves in offshore conditions, and wind/icing in cold climates. If the site conditions and the resulting loads are better evaluated a cheaper wind turbine would be able to reduce the LCOE up to 15%[18]. Also, depending on site conditions, the life time of individual wind turbines could be increased. For example, if a turbine

[18] Estimate based on May's 2012, "The Crown Estate's Cost Reduction Pathways" tool assuming a 10% higher AEP due to right choice of turbine and a reduction of the turbine costs of 10%, http://www.thecrownestate.co.uk/energy-infrastructure/offshore-wind-energy/working-with-us/strategic-workstreams/cost-reduction-study/

is exposed to climate which leads to 5% lower fatigue loads than it is designed for, it could operate up to 3.5 years longer[19] reducing LCOE by up to 4%.

3.3 Siting (design) of wind power plants

The cost-effective siting of wind farms[20] is an essential part of reducing costs. However, the challenge is to be able to accurately predict the wind conditions to which they will be exposed, in order to choose the optimal wind turbine type and layout. This allows predicting the energy yield with more certainty. The main research topics relating to siting wind farms are:

- Measuring systems (see the "Measurement systems" section 3.1);
- Multi-scale modelling chain (including long term correction);
- Wakes.

3.3.1 Multi-scale modelling chain (including long term correction)

3.3.1.1 Objectives

When evaluating wind and wave conditions we have to deal with processes that occur from micro- to macro-scales. The main R&D objective is to develop and evaluate methodologies for coupling models for site assessment at different scales. This also leads to the establishment of consistent methodologies for long term correction of observations and model predictions as well as extreme winds. As a by-product, methods to accurately assess uncertainty will be developed. The models will also be capable of providing simulated wind speed time series needed as input to grid and power system planning. Other objectives are:

- The coupling of meteorological models covering all scales from long term wind speed variations down to turbulence and addressing wind-wave interactions;
- To evaluate the influence of natural climate variability and climate change on wind resources and risks (e.g. tropical and other storms, hot climates and icing);
- To certify compliance of long term reference time series based on global and meso-scale model outputs and to elaborate recommendations on their usage, including new scaling methodologies.

Current levels of uncertainty for complex terrain and offshore projects are about 15% and 10%, respectively. The models must be improved such that, given the geographic coordinates of any wind farm, predictions with an uncertainty of as little as 3% can be made. Such reductions in uncertainty will improve the IRR of complex terrain and offshore projects about 5% and 3% respectively, while the equity input can be reduced by 56% and 33% respectively depending among other factors on the project size and finance structure, both significantly reducing LCOE.

3.3.1.2 Research priorities

The following research priorities have been identified:

- To describe flow at coastal sites, over forested, heterogeneous, hilly and mountainous terrain, which is the backbone of flow models for heights above 100m. They should include the influence of baroclinity[21] both offshore (especially at coastal sites) and onshore;
- Better understanding of offshore-specific flow effects (for example, land/sea transition, high wind profiles, and atmospheric stability);
- Assessing reanalysis and meso-scale products' consistency across time, space, quality and uncertainty, as well as their potential use as long-term correction alternatives;
- Development and adaptation of scaling methodologies for better consolidation and integration of new data into long term uncertainty assessment procedures, including extreme winds;
- Development of optimisation tools for the design of wind farms load- and production-wise taking into account environmental impacts in cumulative scenarios;
- Development of a global extreme wind atlas with a database based on data reanalysis from different models, including methods to increase the spatial resolution through the use of detailed models (CFD and others);
- Identification of other sources of extreme climatic parameters and quantification of values in terms of probabilities;
- Better assessment of long term variability (i.e. decadal fluctuations);

[19] Source: ROMOwind and Tindal A. (2011), Financing wind farms and the impact of P50 and P90 yields, EWEA Wind Resource Assessment Workshop.

[20] From now on the term "wind farms" refers to both wind farms and wind farm clusters. A wind farm is a group of turbines located in the same area, generally of the same type/dimensions. A wind farm cluster is a group of wind farms (at least two) located within a distance such that flow effects in wind conditions occur between them.

[21] Here baroclinity can be seen as the influence of the horizontal temperature gradients on the wind speed.

- Formulation of a classification scheme for high frequency extreme wind changes and provision of a proper statistical prediction;
- Integration and assimilation of wind data into the models, particularly remote sensing data.

3.3.1.3 Impact

The outputs of the model chain can be used to minimise long term wind resource uncertainty and maximize its accuracy, which will have a significant effect on the techno-commercial risk and on estimations of AEP. The ability to properly estimate extreme winds and the reduction of the statistical uncertainty of extreme values will substantially improve the estimation of mechanical loading. The precise knowledge of climatic conditions, including icing, will enable optimal wind turbine configuration for each site.

During wind farm development, the improved methods will help to reduce costs by improving site identification as well as optimisation of on-site measurement campaigns.

Emerging markets and offshore areas will substantially benefit from having compliant and verified products and methods to assess wind conditions (including long term assessment).

3.3.2 Wakes

3.3.2.1 Objectives

Improved cost competitiveness of wind energy comes with the reduction in the uncertainty of wake models, particularly when dealing with large wind farms in offshore conditions where wakes have the highest impact on power, loads, and climate conditions. Consequently, the main objectives are to reduce uncertainty through:

- Developing frameworks for wake model validation, especially when dealing with deep-array effects;
- Understanding the interaction between wind farms and between the wind farms and the atmosphere, the ocean and the climate.

Optimisation of wind farm layouts based on improved wake models could reduce wake losses by up to 20%[22]. Moreover, this optimisation reduces turbine loading, which in turn increases wind turbine life time. The reduced wake losses alone translate into a reduction of cost of energy of up to 2.3%[23]. Implementation of wind farm control strategies can further cut the cost of energy through reducing wake losses and turbine fatigue loading.

3.3.2.2 Research priorities

The following research priorities have been identified:

- Collection and analysis of wake observations including complete wind farm operation and climate data;
- Benchmarking and validation of models for a variety of wind farms, as well as atmospheric and operational conditions;
- Quantifying and reducing the uncertainty of wake models in large wind farms;
- Estimating the impact of the wakes at different scales (micro- and meso-scale, and regional levels);
- Development of wind farm control strategies (alone and in clusters).

3.3.2.3 Impact

The impact on the power output of underestimated wakes in new wind farms is likely to range from 5% to 20%. Improving wake prediction is therefore a top priority. An optimal design of cluster layouts can only be achieved with more accurate wake models. Simultaneously, bankability will be achieved more easily when an effective reduction of the wake uncertainty is achieved. In this way, economically sustainable and intelligent wind farms will be the basis of Europe's future energy system.

Understanding the interaction between wind farms may enable the impact of large wind farm clusters on the meso-wind potential to be assessed. This is particularly relevant for offshore.

3.4 Grid Operation

In the operational phase of wind farms, the aim is to minimise operational cost and maximise power output. Wind and other external conditions play a major role in the control of wind turbines, wind farms and power systems. In addition to the current conditions,

[22] Source: DONG Energy.
[23] See note 18.

forecasts covering different time scales for future conditions are crucial for controlling the operation of wind farms and power systems. Also, condition monitoring and predictive maintenance are dependent on this knowledge of external conditions.

In this area, two main research topics have been defined:

- Wind power forecasting for power system operation;
- Condition dependent construction, operation and monitoring.

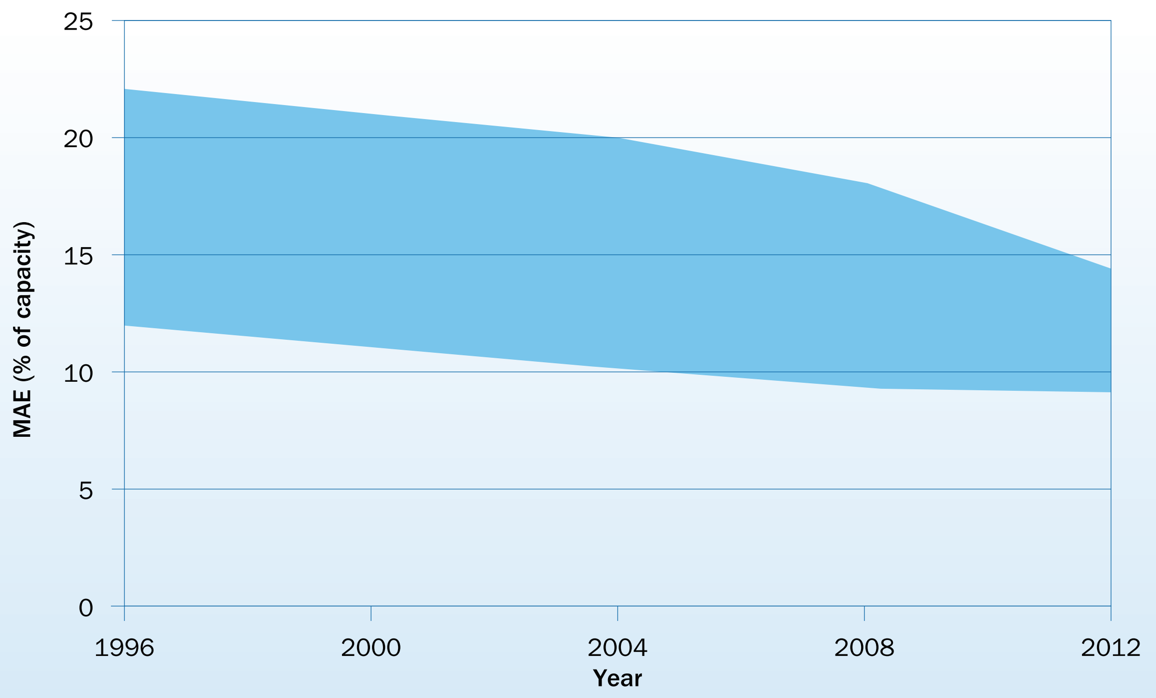
3.4.1 Wind power forecasting for power system operation

3.4.1.1 Objectives

The objective is to obtain optimised wind power forecasts for the entire power system operation including trading, grid operation, maintenance planning, etc. This requires forecasts in different timeframes (from below one hour up to seasonal forecasts of several months), different spatial scales (from wind farm scale up to balancing zone scale) and with different characteristics.

The error in wind power forecasts has been substantially reduced in the past as a result of R&D supported by different stakeholders such as the European Commission, the member states, and the industry (see figure 3). This is expected to continue. For trading, a reduction of the day-ahead forecast error of 35-45% until 2020 seems realistic, according to the DENA II study[24]. This will reduce the cost of energy by reducing the need for reserves and balancing energy. The use of advanced shortest term forecasts in future market rules will have an even greater impact. Both developments can avoid an increase in reserves due to wind power integration[25]. The use of probabilistic forecasts will further improve performance. Overall, the development of new forecasting methods for trading could substantially lower the cost of energy in Europe.

FIGURE 3 REDUCTION PROGRESS OF WIND POWER FORECAST ERROR OVER TIME



Source: GL Garrad Hassan presentation at EWEA 2012

[24] http://www.dena.de/en/projects/renewables/dena-grid-study-ii.html
[25] Ibid.

In addition to trading and power plant scheduling and dispatch, wind power forecasts will become increasingly important for grid security and operation, as wind penetration levels increase in Europe. The ability to address extreme events, such as rapid changes in wind speed (ramps) and direction as well as icing events in cold climates, is of great importance for both forecasting and warning systems. Forecasts with spatial resolution of grid nodes are needed for load flow analysis. As these forecasts aim to improve the security of supply, their monetary value is difficult to estimate. It is however, potentially huge as forecasts are always associated with uncertainties and risks. Consequently, reliable probabilistic forecasts of wind power production will have to be developed together with the best methodology to apply them to grid and power system operation.

Research is needed both in the fields of wind power forecasting and meteorological forecasts on the planetary, synoptic, and meso-scales. In the future, forecast models should make optimal use of all available information (for example, weather predictions, instantaneous power and wind measurements and remote sensing measurements). The vision is to integrate all online (readily available) measurement information (meteorological as well as wind power), the meteorological forecast models, and the wind power forecast models into one improved forecasting system.

3.4.1.2 Research priorities

Research priorities are:

- Better information about the current state of the atmosphere and power production through new or improved measurement techniques and strategies;
- Development of integrated forecasting models including all available online data, NWP models and wind power forecasting models;
- Development of specific wind power forecast systems for the different needs in the operation of the power system, e.g. for short term prediction of extreme high frequency wind gusts, ramp forecasts for warning systems, forecasts with grid node resolution, forecast scenarios, forecasts and maps of predictability, etc;
- Improving probabilistic wind power forecasts and transforming the information into a forecasting system suitable for daily operation.

3.4.1.3 Impact

By 2030 wind power forecasting systems should not only offer greater accuracy, but also serve different needs using specific models. There will be specific wind power forecast models for market integration tasks, for grid operation tasks, etc. To achieve this, new methods will have to be developed (integrated models, probabilistic forecasting and warning systems) and introduced into operations.

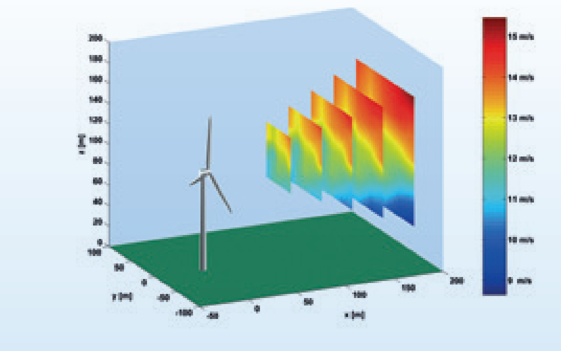
3.4.2 Condition dependent construction, operation and monitoring

3.4.2.1 Objective

The increasing size of wind turbines as well as their siting in remote and offshore environments requires an improvement in the operation, monitoring, and maintenance of the turbines. The measurement of the inflow on the rotor and its analysis will be an integral part of future condition monitoring, structural health monitoring, turbine control and wind farm control systems, also useful for predictive maintenance. Consequently, measurement systems and analysis methods for the inflow of operating turbines need to be developed. The most promising techniques to date are based on remote sensing, particularly using lidar (see Fig. 4). The main objectives are:

- Intelligent control of wind turbine and farm power production, and operation and maintenance using remote sensing techniques;
- Advanced methods for turbine monitoring and operation (condition monitoring systems, predictive maintenance, online diagnostics, etc.);
- Turbine power curve measurement techniques by nacelle mounted remote sensing devices.

FIGURE 4 WIND FIELD MEASUREMENTS USING WIND LIDAR SCANNERS



Source: SWE, University of Stuttgart

Construction and O&M work at offshore turbines is costly and highly weather dependent (see Fig. 5). Optimised planning strategies with integrated simulation of weather conditions and specific weather forecasts for offshore work are important for reducing the cost of offshore work as this is a substantial part of the LCOE of offshore wind farms. Seasonal and long term forecasts are another instrument to improve planning and work scheduling. Here, not only wind, currents and waves should be considered, but also environmental conditions like lightning, icing, sea ice, etc.

For future large turbines, an improvement in energy production of 1-2% due to advanced control seems possible, while the cost increase due to the wind energy system will be small. Improved turbine monitoring and operation reduces the cost of O&M and improves power production due to increased availability. Overall, a reduction of LCOE of 3% is estimated. For offshore wind power, a larger cost reduction can be assumed by also optimising planning and scheduling of offshore work.

3.4.2.2 Research priorities

The following research priorities have been identified:

- Development of measurement techniques to monitor the inflow over the complete rotor of an operating turbine;
- To develop analysis to provide the information needed by new turbine control and wind farm control algorithms, which improve the plant performance (production and/or lifetime) by taking into account online measured inflow to the rotor(s) (in cooperation with the Wind Power Systems Working Group);
- Development of analysis to provide inflow information for new technologies that estimate the state and residual lifetime of the turbines and the power plant based on structural monitoring for predictive maintenance measures (in cooperation with the Wind Power Systems Working Group);

FIGURE 5 ALPHA VENTUS WIND FARM COMPLETED (LEFT) AND IN HARSH WEATHER CONDITIONS DURING CONSTRUCTION (RIGHT)

Source: SWE, DOTI / BSH

- To develop processes for online diagnostics and prediction of the structural health of wind turbines based on the online measured inflow to the rotor and power/load measurements (in cooperation with the Wind Power Systems Working Group);
- Planning strategies and simulation of work processes with integrated weather impact for construction and service of offshore wind farms as well as seasonal and long term weather and wind power production forecasts.

3.4.2.3 Impact

An intelligent control of wind turbines and farms based on measured inflow wind fields offers new possibilities for improving turbine efficiency, especially for large rotors. Advanced methods for turbine monitoring and operation, which use the knowledge about the measured actual wind input on the turbine, will improve turbine availability and reduce O&M cost. Realistic and integrated consideration of weather impact on offshore work will lead to optimised construction and service planning for offshore wind farms.

3.5 Standardisation

3.5.1 Objectives

The improved knowledge of the climatic conditions, interaction between the wind turbine and the wind flow as well as wake-induced loadings, has to be introduced into the standards for structural design. A standard for site assessment also needs to be developed, including recommendations for both onshore and offshore measurement campaigns, and methods for data analysis required as input for the revised load cases.

A standardised uncertainty analysis methodology is needed to estimate the AEP of wind farms as well as for forecasting. Therefore, the main goal is to assess the uncertainty distribution of the different parameters used for AEP estimation and to develop a methodology to predict their combined effect.

Measurement of offshore power curves requires specific standards that should incorporate advanced measurement techniques and assess the influence of the offshore environment on the performance of wind turbines.

3.5.2 Research priorities

- Development of standards for structural design based on advanced modelling techniques and additional and more accurate information on wind operational conditions;
- A standard for onshore site assessment has to be developed considering all relevant steps from the measurements to the modelling and reporting. The standard should cover the typical sites and conditions where wind farms are installed (different terrain complexity, cold climates, etc.);
- Development of design and test standards with classification methods for cold climate instruments and turbines including icing wind tunnel requirements, test condition definitions, and verification with low uncertainty;
- Focus on uncertainties is needed:
  - Mathematical/physical formulation of the uncertainty of wind farm siting parameters;
  - Experimental campaigns aimed to quantify uncertainties;
- Development of a specific standard for wind resource assessment offshore. Measurement techniques including remote sensing (lidars and satellites) should be considered as well as techniques to measure parameters related to waves and currents;
- Specific standards for offshore power curves must be developed. Innovative measuring technologies should be considered (nacelle lidars, floating lidars etc.), as well as the effects of the offshore environment (waves) on the power curve.

3.5.3 Impact

With a complete revision of the relevant standards and the formulation of the missing ones, the uncertainty both in turbine design and site evaluation will be reduced and, as a consequence, the techno-commercial risk. Standardisation helps the industry to streamline production, improve bankability and reduce safety margins. Site assessment is not properly covered by existing standards leading to a suboptimal design of wind turbines and wind farms. Accelerating the acceptance of advanced measuring techniques is required to reduce uncertainty. This has to be supported also by new standards. Standardisation should be considered as an objective in R&D programmes and projects to ensure a proper transfer of knowledge between the research community and the industry/market.

4 WIND TURBINE SYSTEMS

2030 objectives

The aim of TPWind research priorities is to ensure that by 2030 wind energy is the most cost effective energy source on the market. This can only be achieved by developing an efficient and cost competitive generation of wind energy plants while making grid integration more efficient at high wind power penetration rates. TPWind focuses on technological issues of wind power plants, of which wind turbines form the core elements. Both offshore and onshore wind turbines are addressed in this section.

The average levelised cost of wind energy offshore can be reduced by roughly 50% in the next 20 years. Onshore the cost reductions are smaller but could be as high as 20%. The results will depend among other factors on market growth rates, wind resource quality and the learning curve of the industry. The initial investment cost for the wind turbine offshore has a larger effect on the cost of energy than for land based turbines. Increasing the reliability of wind turbines, its components and wind power plant subsystems also have important effects on the cost of energy. For instance increasing reliability will decrease maintenance and thus lower the cost of O&M. Further the loss of energy due to outages will be limited.

R&D priorities are based on their potential to minimize the cost of wind energy and to reduce the uncertainties associated with the development of wind power plants by using probabilistic methods for design and operation. Uncertainties are reduced through a better understanding of the relevant physical phenomena and through experimental verification. Reduction of lifetime costs comprises maximising reliability and cost effectiveness of wind turbine components, which can vary from component to component.

Power plant costs can also be reduced by investigating the optimum wind turbine dimensions (up scaling), reliability level and advanced concepts (complete wind turbines, sub systems and components) for various applications, like offshore and remote sites.

Research topics are categorized according to scientific and technical disciplines underlying the development, construction, operation and maintenance of wind power systems. Seven research areas have been identified:

1. Wind turbine as a flow device;
2. Wind turbine as a mechanical structure/materials;
3. Wind turbine as a grid connected electricity plant;
4. Wind turbine as a control system;
5. Concepts and integration;
6. Operation and maintenance;
7. Standards.

Each research topic is described in the different sections of this chapter.

4.1 Wind turbine as a flow device

4.1.1 Objectives

With the increasing size and complexity of wind turbines, rotor design models and verification methods must include physical aspects that could be ignored for smaller turbines. These physical aspects relate mainly to the size of the rotor blades, which are so large and flexible that deformation and non-linearity coupled with aerodynamics cannot be ignored. A better understanding of aerodynamic phenomena is required, as well as more advanced aerodynamic modelling developed through better physics simulation, to achieve optimal designs. These must include external conditions such as the wind speed distribution on the rotor for different wind turbine configurations and sites.

The R&D objective is to develop and verify accurate design tools. They should take into account all relevant flow interaction phenomena and improve the integrated aero-servo elastic modelling with complex wind flow and wakes, interacting with very large and flexible rotors. The challenge is to develop tools combining all this with the appropriate speed of calculations, more efficient verification tools/methods and higher accuracy for each design stage.

4.1.2 Research priorities

Research priorities include:

- Creating advanced (e.g. CFD and aero elastic, servo-elasticity and control) models and verification methods that take into account all relevant physical phenomena (including complex inflow caused by wakes). This is particularly important for large optimised and thus more flexible rotors featuring fully integrated aerodynamic flow control devices and associated control strategies. Moreover, changing surface roughness on blades should be taken into account;
- Developing new aerodynamic optimisation design approaches including active and/or passive aerodynamic devices and the effects of other wind turbines, wind turbine interaction, boundary layer meteorology. The design approach is to be used for optimising costs, power performance and loading (see also chapter 3);
- Research into the physics of rotor response to upwind wind turbine wakes. The results are to be integrated in design tools (see also chapter 3);
- Development of probabilistic approaches to incorporate uncertainties in aerodynamic modelling; use of tests and measurements for uncertainty quantification and modelling reliability of flow control devices;
- Research significance of external design conditions, such as wind conditions, temperature, humidity, air salinity and earthquakes and their quantification.

4.1.3 Impact

The rotor is the primary energy conversion component of a wind turbine. It also creates the main dimensioning loads for the rest of the wind turbine structure. New, more advanced, design tools will enable the development of larger blades, more rational structural designs and more efficient use of materials. Improved advanced verification methods will lead to more accurate optimisation of blade and rotor designs in which advanced control features could be integrated. Turbines in wind farms should be dimensioned and rated individually, but also with respect to their interaction with other turbines on the wind farm and to optimise grid integration. This should be achieved with advanced control strategies that also consider the performance of the whole wind farm.

Rotor-related research will have an impact on many other wind turbine components and sub systems and is essential to optimise energy production and structural loading, reducing the wind power system's energy costs.

4.2 Wind turbine as mechanical structure/materials

4.2.1 Objectives

The objective is to optimise the use of construction materials and improve the structural integrity of a wind turbine through:

- Increased accuracy of design loads, through modelling and experiments aimed at enabling a probabilistic design approach;
- The use of new high performance structural materials and alternatives to existing materials whose market prices are very uncertain, such as rare earth materials (neodymium) for permanent magnet generators;
- Accounting for the effects of size, weight and the impact of environmental parameters;
- Development of more efficient modelling for predicting damages and cracks prediction and for repair techniques;
- New and less material intensive designs and manufacturing methods;
- Improved methods for verifying structural strength and reliability of components, such as drive trains, bearings, blades and towers. In particular, the structural design of blades needs to be based on more advanced methods to model and verify strength;
- R&D leading to material properties that assure appropriate recycling, preferably maintaining the original material characteristics at the end of a turbine's life;
- Improved methods to verify remaining fatigue strength after the formal design lifetime and development of more reliable methods to extend the lifetime of wind turbine structures;
- Better performance/cost ratio of composite materials preferably in combination with higher strength and stiffness to weight ratios;
- Specification of external conditions and their implication for structural design;
- Improved measures to resist external impacts, such as protective surface layers on rotor blades.

4.2.2 Research priorities

Research priorities include:

- Methods to achieve tailored structural characteristics of components;
- Improving knowledge about design loads for wind turbine components and sub systems in order to enable suppliers to improve their products and contribute to further cost reductions of wind turbine plants;
- Improved characterisation of material properties, including fatigue and compression properties, size effects and recycling possibilities;
- A better understanding of the relation between processing conditions and resulting processing defects and material properties;
- Development of composite materials and material interfaces with higher damage tolerance, higher strength and longer fatigue life;
- Continuous development of design and verification methods to improve structural strength and reliability of components;
- Developing methods to extend the formal lifetime of wind turbine systems;
- Establishing a European virtual wind energy materials research centre, mainly working in materials characterisation.

4.2.3 Impact

The use of more accurate design loads combined with tailored components and the use of damage tolerant materials and designs, will increase reliability (and thus availability) of wind turbine plants and reduce the need for inspection and repair. More accurate design loads combined with better material models will enable better use of materials properties, reducing uncertainties and potentially reducing safety design margins. This will reduce the amount of materials required and lower manufacturing costs without compromising safety levels.

4.3 Wind turbine plant as a grid connected electricity plant

4.3.1 Objectives

The electric conversion system (generator and power electronic converter including control systems) is a key component of a wind turbine, providing the essential features of modern wind turbine plants such as optimising power output, improving power quality and fulfilling grid service requirements like fault ride through capability and grid stability. Reliability, efficiency and cost need to be further improved. The higher the penetration rate of wind energy in the grid, the less important it is to maximise its energy output (in terms number of equivalent full load hours per year) compared to controllability. Consequently, relevant R&D objectives are:

- Improve the capacity of electric conversion systems to reduce energy generation cost and enable innovations in the entire wind turbine plant;
- Minimise the effect of the grid on wind turbine design;
- Investigate the influence of the wind farm configurations on grid support services.

4.3.2 Research priorities

Research priorities include:

- Development of dedicated high-voltage electronics in order to increase efficiency and reduce costs of electricity transport within wind farms;
- Enhancement of power converters to maximise system efficiency and enable advanced control strategies and grid support services;
- Development of new, lightweight, low speed and low maintenance generators, including super conductors to substitute rare earth materials use in permanent magnet generators;
- Extension of design standards to include grid code requirements on an international level in order to facilitate interconnecting local or regional grids and international trading of electricity.

4.3.3 Impact

Improved power electronics, power converters and new generators will have a positive impact on the LCOE as they will enhance the grid compatibility of wind turbines avoiding investments in auxiliary external equipment. Additionally, extending design standards to grid connection requirements on an international level will reduce balancing costs associated with wind energy integrated in the grid system.

4.4 Wind turbine as a control system

4.4.1 Objectives

The objective in the area of control in wind turbines and wind farms is to optimise the balance between power performance, noise emission, mechanical loading and lifetime. This will be achieved through the development of dedicated sensors and actuators, control strategies and condition monitoring systems.

4.4.2 Research priorities

Research priorities are:

- Control optimisation of grid services provided by wind turbines;
- Optimisation of power output and capacity factor for individual wind turbines and wind power plants;
- Increased control system efficiency to manage loads including extreme events and mechanical loads on the wind turbine structure;
- Development of control algorithms to ensure the aero-elastic stability of wind turbines;
- Development of dedicated sensors and actuators, such as lidar, in order to predict the flow in the rotor plane during operation and incorporate this information into the control strategy (see also chapter 3);
- Development of integrated wind turbine system control, condition monitoring systems and O&M procedures.

4.4.3 Impact

Advanced control strategies, as the ultimate integrators of wind turbines and wind power systems, will enable new and improved wind turbine designs incorporating an optimum balance between energy production over lifetime, availability and safety.

4.5 Innovative concepts along the value chain and integrated design

4.5.1 Objectives

The objective is to achieve a reduction in the LCOE by developing highly innovative wind turbine concepts, including substructures. This requires full deployment of design tools including probabilistic design methods. Together with an integrated design approach and through incremental improvements in technology, further cost reductions are possible. This requires risk based strategies involving fundamental changes in wind turbine design (such as floating offshore wind turbines for deep water sites). These radical concepts may often result in high risk projects, so there is a need for risk sharing.

4.5.2 Research priorities

Research priorities include:

- Development of innovative wind turbines and subsystem concepts, in particular, advanced rotor designs for very large wind turbines for offshore applications (including floating wind turbines);
- Development of integrated, reliability and risk-based design optimisation methods (probabilistic design methods) that can cope with new design concepts and uncertainties;
- Development of wind turbine concepts with fewer components including (embedded) sensors to improve reliability and fault tolerant designs enhancing system reliability;
- Development of simulation codes for new concepts;
- Manufacturing methods providing flexibility to tailored (segmented) blades for individual turbines in wind farms;
- Increased manufacturing capacities in existing production systems;
- Failure mode analysis as an input for machine safety and reliability approaches in design;
- Support schemes for risk sharing when developing radical designs.

4.5.3 Impact

Integrated design tools will lead to a design methodology that optimises the entire wind turbine. They will also lead to more realistic industrial design requirements for turbine components. This systematic approach, coupled with the development of innovative, higher risk concepts, has the potential to dramatically reduce the cost of energy.

4.6 Operation and maintenance

4.6.1 Objectives

Operation and maintenance (O&M) strategies become more critical with upscaling and deployment of wind power systems offshore and in other difficult to access sites such as cold climates, mountainous terrains and desert areas. The objective of this research topic is to optimise O&M strategies in order to increase availability and system reliability and to reduce the cost of inspection and repair. This can be achieved by gradually replacing corrective maintenance with preventive and condition based O&M. The development and implementation of these strategies becomes more urgent when wind turbines become more complex and more difficult to access. In particular this applies to future deep water floating wind turbine systems.

4.6.2 Research priorities

Research priorities include:

- Failure identification, through investigation of faults in wind turbine components and their effects, including characterisation of damages and crack growth e.g. through built-in sensors (condition monitoring or Structural Health Monitoring – SHM);

- Integration of condition monitoring and fault prediction capabilities into the wind turbine's control system;

- Development of sensors and associated analytical tools to determine remaining lifetime;

- Development of highly reliable (damage tolerant) repair methods and strategies;

- Development of methods for easy replacements of components for remote/difficult to access sites and sites that can only be accessed during short time windows;

- Development of methods to verify repairing techniques' efficiency e.g. for offshore application including alternatives for cranes;

- Development of maintenance strategies involving preventive, risk based inspection techniques using condition monitoring and other indicators;

- Development of dedicated access technologies for O&M purposes, in particular for remote sites, such as (deep water) offshore, cold climate and desert areas. This enables more time per year safe access to remote wind turbines in order to increase the O&M weather window;

- Development of new options making repairs considerably easier and efficient, such as towing the turbine to a dock side for maintenance/repair; lifting operations on floating turbines, etc;

- Design for efficient O&M strategies e.g. based on feedback from field service experience.

4.6.3 Impact

The proposed research will lead to improved O&M strategies that will reduce O&M costs and increase confidence in their value over the lifetime of a wind project.

The positive impact on the cost of energy is due to 1) lower cost of O&M resulting from fewer failures requiring (corrective) maintenance and repair and 2) lower cost of structural components through reduced risk of failures due to less design load cases (DLCs) taken into account. Furthermore the duration of outages will decrease and the wind turbine output will increase significantly reducing current corrective maintenance costs.

4.7 Standards & certification

4.7.1 Objectives

The objective is to continuously update existing standards and develop additional standards for wind turbine design and testing (e.g. standards for floating wind turbines). This will enable technological advances and cost reductions while maintaining confidence in the safety, reliability and performance of the turbines.

Improvement in standards for design and testing will support cheaper technical solutions, as they will be based on extensive research. To this end, standards shall focus on wind turbine specific issues with high cost impact such as loads, control systems, blades, towers, foundations and electrical/mechanical transmission components. At the same time, standards should allow for the greatest flexibility, when it comes to optimising the cost of wind energy. While they are extremely valuable to ensure safety under the lowest possible costs, this is only accomplished when they are kept on a realistic requirement level and they are updated accordingly to reflect technology progress or industry general accepted practices. In this sense, standards should create transparency on quantification and mitigation of technical risks.

Clear and effective certification procedures should accompany the maturing of the wind industry and the increasing complexity of technical solutions. A better system alignment of different technology certifications as well as the quality systems is required.

4.7.2 Research priorities

Research priorities include:

- Adjusting the wind turbine load and safety standard to support probabilistic/risk based design and use advanced control systems and sophisticated tools for design and testing;
- Developing standards for new technologies e.g. floating offshore wind turbines;
- Research to support the development of a blade design standard that allows for the use of advanced load control, advanced composite materials and advanced design tools;
- Further development of testing standards for very large blades to optimise processes and risk mitigation;
- Development of design and testing standards for large blade bearings based on experience from condition monitoring and theoretical modelling;
- Development of design and testing standards for large wind turbine components that account for a wider range of uncertainties (physical, statistical, modelling and measurement) and integrate information from tests at different scales (coupon, subcomponent and full-scale tests) in order to achieve low but highly reliable test uncertainties that reduce safety margins;
- Development of standards addressing the use of materials in large size components e.g. cast iron and advanced concrete;
- Development of standards for electrical equipment such as generators, converters and transformers with focus on lifetime costs;
- Integration of experience from operational wind farms to allow continuous refinement of wind turbine technology and quality systems;
- Development of a more systematic certification framework where aligned requirements for technology and quality systems are driven by a risk based perspective (e.g. the highest impact on risk handling is achieved with the smallest effort);
- More efficient certification procedures e.g. self-certification.

4.7.3 Impact

The proposed research will improve confidence in future investment in wind farms, both during the development and operational phase. Standards of wind farms, wind turbines, sub systems and components will facilitate “exchangeability” of parts and lead to more cost effective manufacturing and assembling processes while avoiding expensive failures.

Also, this research topic will reduce the cost of wind energy and risks through improved standardisation and certification. The research concentrates on key areas where the uncertainties and inaccuracies are the highest, therefore where the impact will be the greatest.

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5 WIND ENERGY INTEGRATION

2030 objectives

The future power system will be dramatically different from today's. It will become the backbone of the total energy supply, including electricity, heating and transport. Several hundred gigawatts of generation capacity will be replaced by 2030[26], mostly by renewable generation. Beyond 2030, an average EU-wide wind energy penetration beyond 30% of electricity is envisaged. Wind power fully covering or even exceeding local power demand will be a normal occurrence. How this new power system will influence the demands on design and operation of wind power plants, needs to be clarified.

In this context, the question for wind power integration is no longer whether wind can meet a significant share of electricity demand, but what an economically viable and secure power system based, to a large extent on wind power, should look like. This implies the transformation of the whole power system including wind – and other renewable – energy sources.

Integration of wind power needs to be dealt with at the power system level and not only at the wind turbine or farm level. Also, electricity markets need to evolve in order to move away from dedicated wind support schemes to new business models. To this end, a market structure that properly accounts for the variable nature of wind power is needed.

Therefore, the objective of this research topic is to allow the wind power penetration rate to grow to anywhere between 30%, 50% or 70% in an economic and safe manner, as part of a 100% carbon free power system by 2050 or beyond.

In this context, three research areas are important:

- Wind power capabilities for ancillary services provision;
- Grid connection, transmission and operation;
- Wind energy in grid management and power markets.

Each of these research areas is described in the different sections of this chapter.

[26] "Spare electricity generating capacity is at a historic low and phase-out policies in the EU Member States require 27 GW of nuclear plants to be retired. Europe has to invest in new capacity to replace ageing plant and meet future demand. Between 2005 and 2030, a total of 862 GW of new generating capacity needs to be built, according to the IEA – 414 GW to replace aging power plants and an additional 448 GW to meet the growing power demand. The capacity required exceeds the total capacity operating in Europe in 2005 (744 GW)." EWEA, Pure Power Report, 2009, http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/purepower.pdf

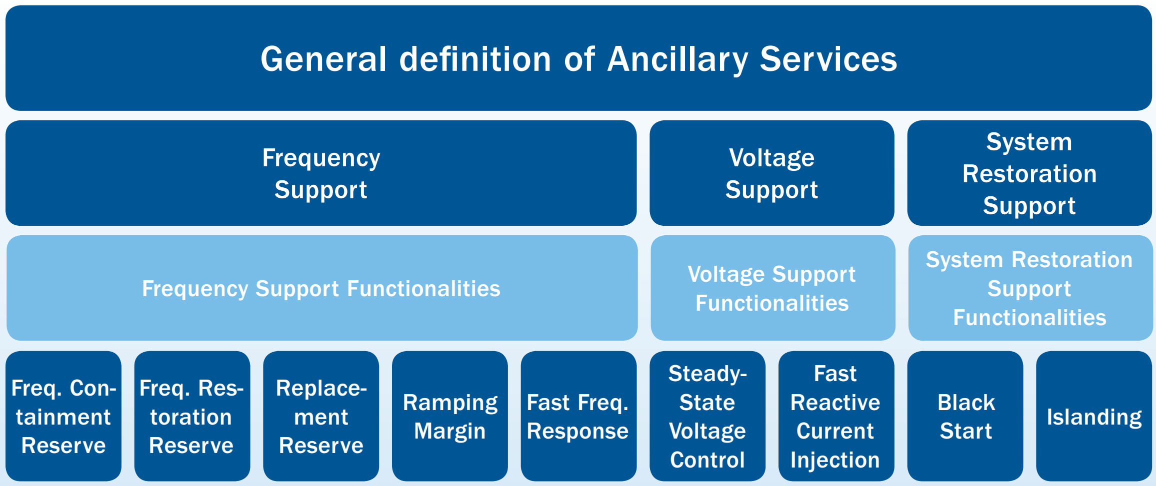
5.1 Wind power capabilities for ancillary services provision

5.1.1 Objectives

While the existing power system is mainly comprised of large power plants located close to consumers and connected to the grid at high voltage levels, the coming renewable generation is being installed close to the resource, which is often far from the source of demand. If this distance is very large, the wind power is connected to the grid via High Voltage Direct Current (HVDC). Renewable generators also come in smaller sizes than the classical power plants, and can therefore be connected at many different voltage levels. To account for those changes at high shares of wind power in the grid, adequate grid support capabilities need to be developed.

Currently, power system security and stability are ensured through the delivery of so-called ancillary services[27] (AS) from synchronous generators. These services include frequency control[28], voltage control[29] and active and reactive power control, among others. The large physical inertia of the rotating masses from conventional generators directly (synchronously) coupled to the grid keeps the power system stable. Adding substantial amounts of non-synchronous[30] wind power capacity to the power system will gradually replace this synchronous generation together with its inherent inertia, frequency and voltage support functions. A main challenge for renewable generation including wind power is therefore the new allocation of these essential functions in the changing power system between the new (wind, solar PV etc.) and the existing power system assets.

FIGURE 6 FOUR-LEVEL HIERARCHY DESCRIBING THE RELATION BETWEEN THE GENERAL DESCRIPTION OF SELECTED ANCILLARY SERVICES, THE AGGREGATED CATEGORISATION, THE FRAMEWORK OF FUNCTIONALITIES AND THE SPECIFIED ANCILLARY SERVICES



Source: REserviceS Project

[27] "Ancillary services" are all grid support services required by the transmission or distribution system operator to maintain the integrity and stability of the transmission or distribution system as well as the power quality. These needs can be fulfilled by connected generators, controllable loads and/or network devices. Source: REserviceS D2.2 "Ancillary services: technical specifications, system needs and costs", http://www.reservices-project.eu/publications-results/

[28] Frequency control: services related to the short-term balance of energy and frequency of the power system; it includes automatic (primary/secondary) and manual (tertiary) frequency regulation and operational reserves. This is the main service provided by generators [...]. It can also be provided from flexible loads, and storage units. Source: REserviceS Project D2.2 "Ancillary services: technical specifications, system needs and costs", http://www.reservices-project.eu/publications-results/

[29] Voltage control: services required for maintaining the power system voltage within the prescribed bounds during normal operation and during disturbances by keeping the balance of generation and consumption of reactive power. Voltage control includes reactive power supply (injection or absorption) and can be provided by the dynamic sources [...] and static sources [...]. In the event of a disturbance to the system, dynamic reactive power response is required to maintain system stability. Source: REserviceS Project D2.2, "Ancillary services: technical specifications, system needs and costs", http://www.reservices-project.eu/publications-results/

[30] Non-synchronous: in modern wind turbines the generator frequency is electrically de-coupled from the network frequency due to the inverter based (AC-DC-AC) grid connection.

Some research work has commenced on the AS topic, but there are still important gaps in knowledge. Currently, the EU-funded project REserviceS[31] has started to lay down the basis for a common understanding of definitions, opportunities and costs of AS provision from wind and PV for an EU wide common AS market.

Figure 6 shows a selection of AS functionalities[32] compiled by this project. Note that the list is not exhaustive – for example, fault-ride through, short-circuit current, power oscillation damping or resynchronising after islanded operation are not described here.

At transmission level, large scale offshore wind deployment involves the need for sharing and coordinating AS functionalities and requirements between clusters of wind power plants and HVDC links, in the most economical way. If the HVDC links are connected with each other to form a grid, potentially also transferring electricity between market areas, the complexity is even greater. On the other hand, at distribution level cost effective methods need to be established for active participation of wind power in voltage and frequency management.

There are several ways to ensure that generators provide the necessary services to the network. Grid code requirements[33], enable network operators to make sure that the system is safe and secure in normal and fault situations and to deliver AS such as frequency, voltage support and system restoration services. Frequency support and active power balancing are utilised across large transmission grids, i.e. over long distances and sufficient transmission channels. However, specific AS are delivered and consumed locally in the grid (e.g. voltage support), and for these cases, new methods need to be developed to find the most cost-effective solution for providing the AS – involving technology development, cost reduction and market design. Once developed, the functionalities and capabilities must be standardised and independently verified, to allow for grid services from wind power to be easily taken up by the grid operators.

Practical experience and studies confirm that the functionalities and capabilities of modern wind power enable power system support for current needs, where the bulk of AS is supplied by large conventional generators. However, substantial research is needed not only to better understand where and how wind power can take up its growing role as ancillary service provider, but also to enable the development of reliable and cost effective solutions to respond to the fast growing needs of grid operators. In conclusion, wind power will need to provide more AS in the future when synchronous generation will retreat. Therefore, enhanced wind power AS capabilities need to be developed as wind penetration increases, for the stability of the grid and to strengthen the business case for wind power. This enhancement of capabilities should go hand-in-hand with the continuous development of appropriate grid code requirements, as well as standards that lower the risk and time taken to market new solutions.

5.1.2 Research priorities

Relevant research priorities for the main technical issues are:

- Further development of enhanced wind power capabilities from wind turbine level up to cluster level, including the related design tools and models;
- Testing and verification of frequency and voltage capabilities, and methods of proving compliance of new solutions for advanced capabilities with grid codes and standards;
- Harmonisation, standardisation and interoperability of methods and technologies for delivering ancillary services with wind power.

Grouped according to the main technical issues frequency (a), voltage (b) and system restoration support (c), the priorities above translate to:

31 www.reservices-project.eu

32 According to REserviceS Project, a functionality is a single technical capability or a collection of them described independently from their technical implementation. E.g.: sensing the frequency deviations. Source: REserviceS Project D3.1 “Capabilities and costs for ancillary services provision by wind power plants”, http://www.reservices-project.eu/publications-results/

33 A grid code requirement is a technical specification which defines the parameters a facility (e.g. an electricity generating plant) connected to a public electric network has to meet to ensure safe, secure and economic proper functioning of the electric system. Source: Wikipedia, accessed 7/9/2013.

a. Frequency support

Methods need to be developed to improve wind power control and capability for system frequency support, especially during fast and large frequency variations which are expected to occur more often as high shares of non-synchronous wind lead to reduced power system inertia. Wind power control strategies that take geographical siting across the network into account need to be developed, to enable aggregated wind power to contribute to system stability, notably by damping power frequency oscillations.

In parallel, suitable power system models and adequate temporal and spatial tools need to be further developed to model the aggregated wind power injection from many dispersed sites, to improve system wide frequency analysis with substantial amounts of wind power. Reducing a model's complexity and ensuring reliable simulation results through validation of models is challenging. But this is needed to validate the capabilities and to improve understanding of the cost and value of fast up- and downwards frequency response and system inertia support, that wind can offer.

The development of advanced frequency capabilities needs to be accompanied by testing and verification. Finally, further development efforts should focus on standardised products meeting the needs of network operators and power producers economically.

b. Voltage support

Voltage management in future power systems with reduced share of large thermal generation needs to be taken up increasingly by renewable generators, along with control by network devices such as HVDC converter stations or flexible AC transmission systems (FACTS) devices. Research into methods for co-ordinated voltage support is needed to determine cost effective ways of sharing the voltage control task, in particular with help of wind farm clusters[34]. This needs to be supported by research on cost effective methods for voltage control with wind power both in normal and fault situations on the network, e.g. by developing enhanced control strategies and lower cost inverters or other scalable technologies. Research is also needed to develop ways that wind power can assist the voltage control and power quality in distribution networks. These are inherently weaker and need enhanced management and protection methods, to enable increased hosting capacity for renewable generation.

The development of advanced voltage capabilities needs to be accompanied by testing and experimental verification, leading to the delivery of standardised products that meet the needs of network operators and power producers.

c. System restoration

Investigation is needed into the role of wind power in system restoration after a black-out. Currently, wind power cannot black-start a grid on its own, and in the absence of large conventional generators alternative methods for black-start have to be found, for instance using storage devices, HVDC links or the distribution level as first energisers of the grid. Research needs to target methods of reliable participation by wind power plants in power system start-up processes.

5.1.3 Impacts

The research in this area is a prerequisite for achieving high penetration targets for renewables. Enabling wind power plants to provide reliable and standardised ancillary services can contribute to improved competitiveness of wind energy in a market with high penetration from renewables. Standardised solutions enable faster procurement for projects, with less need for contingency allowances, leading to reduced capital expenditure (CAPEX).

5.2 Grid connection, transmission and operation

5.2.1 Objectives

A major barrier to large scale integration of wind power is inadequate transmission capacity between remote high wind locations and the larger consumption centres. With the existing wind power capacity, wind energy is regularly curtailed in some regions. The transmission capacity is limited by the physical capacities of the lines and for system security reasons.

[34] Frequency and voltage control by wind farm clusters were or are developed and demonstrated in TWENTIES, Wind on the Grid and EERA-DTOC.

In future more physical transmission capacity and more flexible utilisation of the available capacity are needed, to support further wind power development. This is particularly important for the feasibility of the massive offshore wind power development planned by EU and national authorities, but also to accommodate onshore wind developments in rural areas with favourable wind resources.

Apart from building new lines, which is a long process, transmission system operators (TSOs) investigate technical solutions to be able to get more power through existing lines, for instance Dynamic Line Rating (DLR), Flexible AC Transmission Systems (FACTS), or local storage. DLR is particularly relevant for wind power integration, because it utilises the fact that overhead line capacities increase in stronger winds due to wind induced cooling, which is not taken into account for the thermal limits of the transmission lines.

The connection of wind power plants to HVDC converters is providing experience with systems with zero inertia. This applies for simple point-to-point HVDC links for connection of wind plant to the onshore Alternating Current (AC) transmission system as well as for connection to more complex multi terminal offshore HVDC grids. This experience should be used to investigate areas with very low inertia.

Standardised simulation models of wind power plants are needed to enable network planners' assessment of more wind power being connected and transmitted. To facilitate standardisation, there is a need for continued research into the most appropriate simulation architectures able to model different wind generators and manufacturers' solutions.

5.2.2 Research priorities

The research priorities for grid connection and transmission R&D must be coordinated with the European Electricity Grid Initiative (EEGI). Some of the priorities on the grid side are naturally led by the EEGI, while others, e.g. wind power capabilities, should be led by TPWind. We identified the following research priorities:

a. Development of technologies to provide maximum network transmission capacity of the existing network and optimise the use of wind power at the power system level;
b. Development of methods and tools to support secure operation of power systems with large scale wind power;
c. Development of new concepts considering the entire chain from wind turbine grid connection through wind plant power collection to transmission; and
d. Improvement of methods and tools for modelling, test and validation of the electrical characteristics of wind power.

a. Optimisation of network transmission capacity to utilise wind power

This research priority should contribute to better utilisation of the existing transmission network, and support the assessment of the need for new transmission lines. Methods for probabilistic grid planning should be improved and validated, including planning of overhead transmission lines as well as onshore and offshore cables and transformers, taking into account the influence of the weather conditions on the thermal capacities and time constants. The main focus will be on the static thermal loading, but the dynamic load limitations and stability limits should be taken into account. The temporary overload capability should be included in the assessment of the dynamic loading.

b. Secure operation of power systems with large scale wind power

Probabilistic methods should be applied in the power system security assessment. The wind power community should contribute to this with models and parameters describing wind power variability and predictability.

New control and protection schemes should be developed to replace the present need for inertia to support frequency stability in the power system. Experience with HVDC connected offshore wind power plants should be included, as this is the ultimate system with zero inertia. This HVDC case needs to be further developed to apply to systems where the frequency is not set by a single master converter but coordinated by all the converters in the system.

c. New concepts for grid connection, power collection and transmission of wind power

Coordination of the entire electrical chain from turbines, through the wind plant power collection grid up to and including transmission, offers significant savings on investment costs and electrical losses. Power collection and transmission at DC or 16.7 Hz are two candidate technologies. Also higher nominal voltage levels in the power collection grid will reduce losses and costs for cables and platform, but this will increase costs of some equipment in wind turbines.

There are also relevant alternatives to the meshed multi-terminal HVDC solution for the offshore super grid. Thus, hybrid AC / DC solutions could be a feasible alternative. Such solutions should also be explored, technically and economically.

d. Modelling, test and validation of the electrical characteristics of wind power

The technical development to fulfil the new requirements, for example for ancillary services in the grid codes, needs to be followed by modelling, test and validation.

While there is still a need for development of wind turbine test procedures, the main need for test development is on the plant level. The possibilities for full scale plant level tests are limited, because, for example, a full scale short circuit test will be very costly if the test should protect the grid against jeopardizing system security. Still, methods for plant level tests should be developed involving the plant controller and communication system.

The R&D for modelling and validation is required mainly at the plant level. A first generation of dynamic stability models for wind turbines is available, but R&D is needed to enhance those models to cover unbalanced faults in the grid. At the plant level, there is a need for R&D to aggregate multiple wind turbines to a wind power plant model and to model the communication system.

5.2.3 Impacts

Optimising investments in transmission and a better utilisation of the existing transmission network will reduce wind power curtailment and provide opportunities to utilise ancillary services from wind power. Better asset management and standardisation are also factors reducing cost. The grid connection (establishment and life time) cost, particularly for offshore wind power plants, will be reduced through the use of innovative or improved connection technologies and through their eventual interoperability and standardisation. Offshore wind power could get cheaper due to a more integrated design of the electrical system from the individual turbine generator to the collection grid and all the way to the onshore connection point.

5.3 Wind energy in grid management and power markets

5.3.1 Objectives

The future power system, with a much higher share of renewable power than today, will increase price volatility on the power markets and increase the frequency of zero or even negative prices. Very high or low prices occur in times of temporary lack of wind, surplus wind, or when additional power plants need to run just to

provide AS. There is little incentive for adding new or replacement capacity (both renewable and conventional), when the income generated during the fewer periods with high prices is not sufficient to recoup the investment.

However, the regular very low prices may favour converting surplus wind power into storable forms of energy like gas, heat or transport fuel. The controllable conversion facilities would add flexibility to the grid. New business models are needed to support the installation of additional wind power capacity and other types of generation. The relative merit of ancillary services markets should be considered.

The future energy system will probably encompass Europe's neighbouring regions too, and will involve increased cross-border trading of energy and ancillary services in a larger market for next-day and intra-day trading. The principal price fixing mechanism may have to change: the current model of marginal pricing was developed for controllable, conventionally fuelled generation, where the market favours investment in new or replacement capacity. Such incentives will not be adequate in a market with very large shares of weather dependent renewable energy.

Today, grid management is based on deterministic methods. There is R&D into probabilistic methods taking a local and pan European approach, to reflect the uncertainty in renewable power forecasts. This includes changes in procedures like the transition away from (n-1)[35] criterion towards dynamic reserve requirements, or better planning and utilisation of grid assets, such as through DLR of transmission lines or improved local and grid-wide storage management. Switching to a probabilistic paradigm for power system management will be necessary in a future power system with high share of renewable generation.

5.3.2 Research priorities

The overall research priorities are:

- Development of detailed generation, transmission and demand scenarios resolved by year and country to reach a 100% renewable system;
- Development of improved probabilistic tools for power system, portfolio and asset management, intended for high penetration of renewables and taking new business models for generators into account;
- Improved probabilistic generation, demand and price forecasting and use of such forecasts for power system management and market integration;
- Assessment of impacts of high wind energy penetration on power system planning and operations and the adequacy of generation capacity with new and improved tools;
- New market designs and appropriate business models for a power system with high shares of renewable generation, including the efficient link to other energy markets like heat, cold, gas or transport fuels;
- Assessment and demonstration of economic benefits of several options in providing ancillary services and power balancing in higher wind penetration scenarios.

To implement these research priorities, the two R&D topics outlined below need to be tackled.

a. Assessment of wind power in high penetration scenarios towards 2030/2050

In order to support the detailed analysis of future power systems, a set of scenarios for future installations broken down by country and year should be provided. Some countries are reaching higher penetrations earlier, and could provide an example of how variable renewable generation affects the investment possibilities for all new power plants (conventional and renewable alike). The scenarios should include both evolutionary and revolutionary development, and account for political, economic and climate uncertainty. The impacts on power system stability should be quantified using validated and verified models, and ways to operate a synchronous system with more than 75% of non-synchronous generation should be investigated. Finally, a backcasting exercise should start from a future 100% renewable scenario and trace back which installation rates and power system infrastructure are required to reach the final scenario (starting from the current system).

[35] The (n-1) criterion stipulates that there should be at all times sufficient surplus capacity online to allow for the sudden loss of the biggest power system in-feed (often a large power plant, but could also be a transmission line from abroad).

The integration of variable electricity generation in the full energy system should be investigated, both from a market perspective, but also regarding technological options of direct conversion.

A number of countries have already undertaken studies for a 100% renewable future. Since such targets affect the whole European system it is necessary to develop a common European wide open source study model, which combines grid management on both a technological and economic level, and is adaptable for both market and system integration studies. The necessary databases for wind speeds, power system setup, generation mix etc. should also be included. A derived version of this model could be used to investigate DSO/TSO coordinated operation. It should also allow for different market schemes and probabilistic market bidding using improved wind power forecasts.

b. Grid management and markets

At the operational level traditionally deterministic power system management tools need to be converted to to probabilistic tools, in order to safely handle high penetration of renewables and better utilise the probabilistic forecasts. Forecasting improvements are needed for all time scales, not only for renewable generation and weather dependent demand, but also for use in DLR and other techniques that optimise system operation.

Another topic concerns the need for adequate capacity. Wind and solar will change the system, both on a technical and on a market level. With wind power concentrated at the places of the highest resource, and thereby mostly producing at the same time, how should new wind and other capacity be incentivised? A detailed hourly market model coupled to investment models is needed to analyse the capacity adequacy. The withdrawal of peak plant capacity from the system after 1-2 years of low returns must be avoided, and models for conventional generators in grids with high shares of wind/PV should be analysed and developed.

In order to be prepared for the future market environment, we need to develop new business models for wind and solar power, both for energy and ancillary services market operation, including offshore grids connecting several electricity markets and the sale of power to other energy markets (heat, cold, transport, gas).

Additionally, the market design of a power system that has very high shares of wind and solar, needs to be revisited. Alternatives to marginal pricing should be explored in an environment where the marginal or operating cost of the majority of power plants is very close to zero. This marginal price creates problems for existing wind power operators, and is not conducive to adding new capacity. There might be a minimum size for such a market in order to always include conventional power stations, setting a price above zero. This new approach could be based on probability density functions and probabilistic bidding. The extension of this market beyond Europe needs to be analysed.

5.3.3 Impact

The research into grid management and market issues enable to keep up with the pace of current wind power growth without endangering the system at significantly higher penetrations levels, leading to lower costs for the consumer.

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6 OFFSHORE TECHNOLOGY

2030 Objectives

The most critical priority for offshore wind power is to significantly lower its cost of energy in order to become competitive with conventional power generation by 2030. This requires large scale infrastructure for research, development and demonstration, not only for wind turbine structures, but also for the complete life cycle of a wind energy project. This includes design, manufacturing, transportation, logistics, construction, operation, maintenance and decommissioning. An integrated design approach that can minimise the LCOE is targeted by including the site specific boundary conditions in the wind turbine design.

Beside full competitiveness of offshore wind power costs with conventional electricity generation, by 2030, the offshore sector aims to harness commercially mature technology not only for shallow waters sites, but also in sites with a water depth beyond 50m, at any distance from shore.

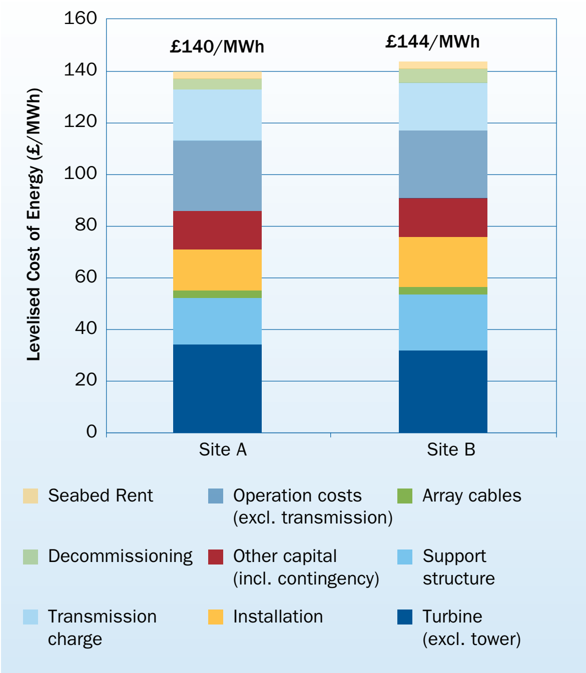
This section addresses issues specifically related to the development of the offshore wind industry. Six research topics have been prioritised:

- Sub-structures;
- Logistics, assembly and decommissioning;
- Electrical infrastructure;
- Wind turbines and farms;
- Operations and maintenance;
- External conditions.

The topics have two common themes, critical to delivering an offshore wind industry in Europe, which is the world leader in the sector:

- LCOE;
- Safety, environment, and education.

FIGURE 7 EXAMPLES OF SITE SPECIFIC COSTS CONTRIBUTING TO THE LEVELISED COST OF ENERGY OF TWO OFFSHORE SITES IN THE U.K.



Source: Offshore Wind Cost Reduction, Pathways Study, The Crown Estate, 2012[36]

The LCOE can be said to depend on these six research topics, as depicted in Figure 7.

Several key performance indicator targets can be used, however, since the LCOE of offshore wind farms is site specific, the following targets will be applied:

- Reduce LCOE by 30% from present levels for similar sites by 2020;
- Reduce LCOE by 50% from present levels for similar sites by 2030.

The key performance indicators to ascertain the progress in meeting the LCOE targets are:

- Wind turbine capacity factors of 50% by 2020;
- Modularisation and mass manufacturing of sub structures;
- 40% reduction in O&M costs from present levels by 2020;
- Reliable and efficient offshore transmission system;
- Minimised soil property uncertainties for site specific sub structure design.

FIGURE 8 OFFSHORE WIND POWER RESEARCH TOPICS AND COMMON THEMES

Source: TPWind

[36] The Crown Estate, "Offshore Wind Cost Reduction", Pathways study, May 2012.

Within each area, there are short to medium term research actions that must be addressed to allow the rapid deployment of offshore wind in Europe's waters. Over the medium to long term, significant research is required to deliver the necessary technical and performance improvements, leading to required cost reductions.

The two cross cutting themes are analysed in paragraph 6.1.1 (LCOE) and 6.1.2 (Education, safety and environment).

Each of the six research topics, are described in the following paragraphs.

6.1 Cross-cutting themes

6.1.1 Levelised Cost of Energy (LCOE)

The LCOE is defined as the sum of discounted wind farm lifetime costs divided by the sum of discounted lifetime energy output (MWh). The costs include all development capital, operating, and decommissioning costs incurred by the wind farm owner/developer over the lifetime of the project. Present LCOE costs for offshore wind farms are site dependent and also depend on the costs of procuring capital and insurance. However, the LCOE of offshore wind energy is currently significantly higher than onshore wind energy and conventional energy sources, despite generally much better offshore resource. This implies that there is a strong need to reduce the LCOE of offshore wind energy in the near term.

6.1.2 Education, safety and environment

All construction, operation and maintenance activities must be undertaken safely, with no harm to people, equipment or the environment. Safe operation of offshore facilities, and the safety of the staff involved in the installation, hook-up, commissioning, and operations and maintenance of these wind farms is vital. Research can cover:

- the examination and review of turbine access systems;
- escape and casualty rescue.

Education must deliver trained people with the necessary skills to develop the industry. This will range from skilled workers needed to manufacture, build and operate the facilities to graduates that understand the technical, commercial and social context of the industry. EWEA estimates that by 2030, more than 790,000 will be employed in the wind energy sector in Europe[37].

6.2 Substructures

6.2.1 Objectives

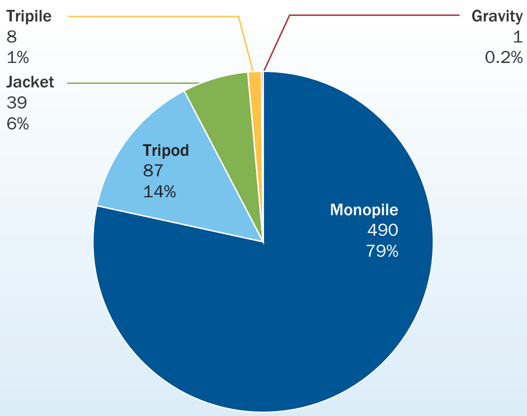
Sub-structures represent a significant proportion of offshore wind energy costs, typically 20-30% of project CAPEX. Therefore novel sub-structure design, optimised manufacturing processes and improved installation methods critical to reducing the cost of offshore wind energy.

Nearly all offshore wind turbine structures developed to date operate in water depths less than 40m. Monopiles are the most common sub structure design, especially where turbines of rated capacity less than 5 MW are used in water depths of less than 30m. Concrete gravity structures have also been used for similar depths and turbine sizes [see figure 9]. Jackets are expected to be more common in deeper water with larger turbines.

As turbine sizes increase beyond 6 MW, and the industry moves into waters deeper than 30m with more challenging soils, improved sub-structure designs are required [see figure 10]. The different types of fixed-bottom sub-structures that are expected to be required for future offshore wind farms are described in Table 2. Developing these fixed-bottom and floating sub-structures will require more sophisticated integrated design methods, better understanding of boundary conditions, material properties and the dynamic loads. These must be coupled with more efficient manufacturing processes and procedures, for example, making use of automation and robotics. Standardised components and modular designs will facilitate serial fabrication once the sub-structure design concepts are sufficiently mature.

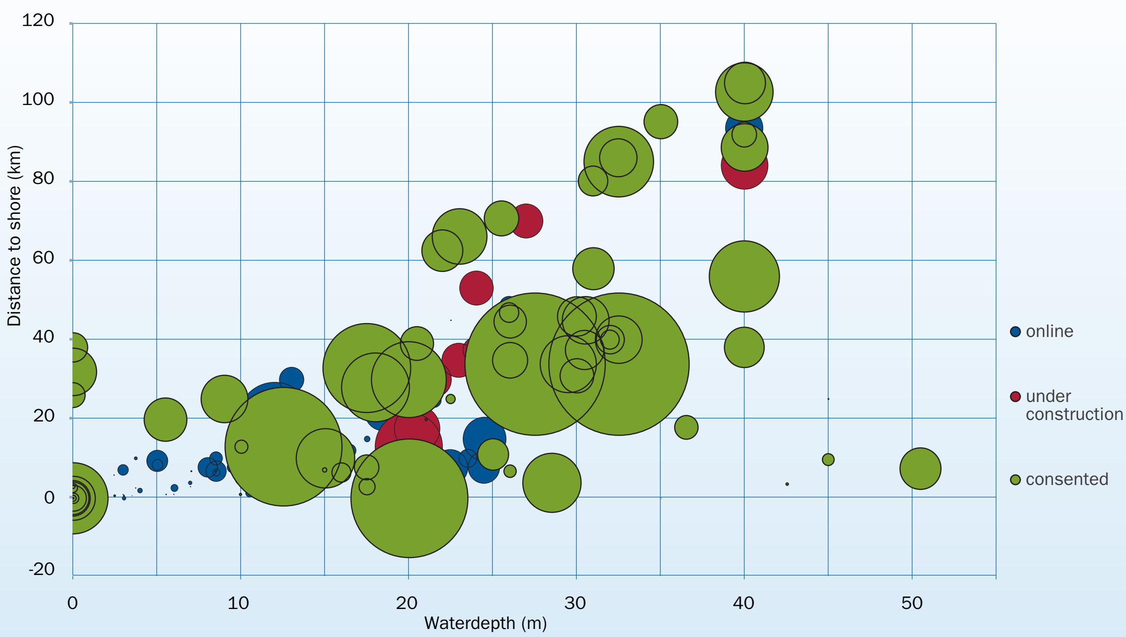
[37] EWEA, "Green Growth - The impact of wind energy on jobs and the economy", April 2012.

FIGURE 9 FOUNDATION TYPES EUROPEAN CUMULATIVE MARKET SHARE 2013



Source: EWEA "The European offshore wind industry - key trends and statistics 2013", January 2014, p7.

FIGURE 10 AVERAGE WATER DEPTH AND DISTANCE TO SHORE OF ONLINE, UNDER CONSTRUCTION AND CONSENTED WIND FARMS



Source: EWEA "The European offshore wind industry - key trends and statistics 2013", January 2014, p9.[38]

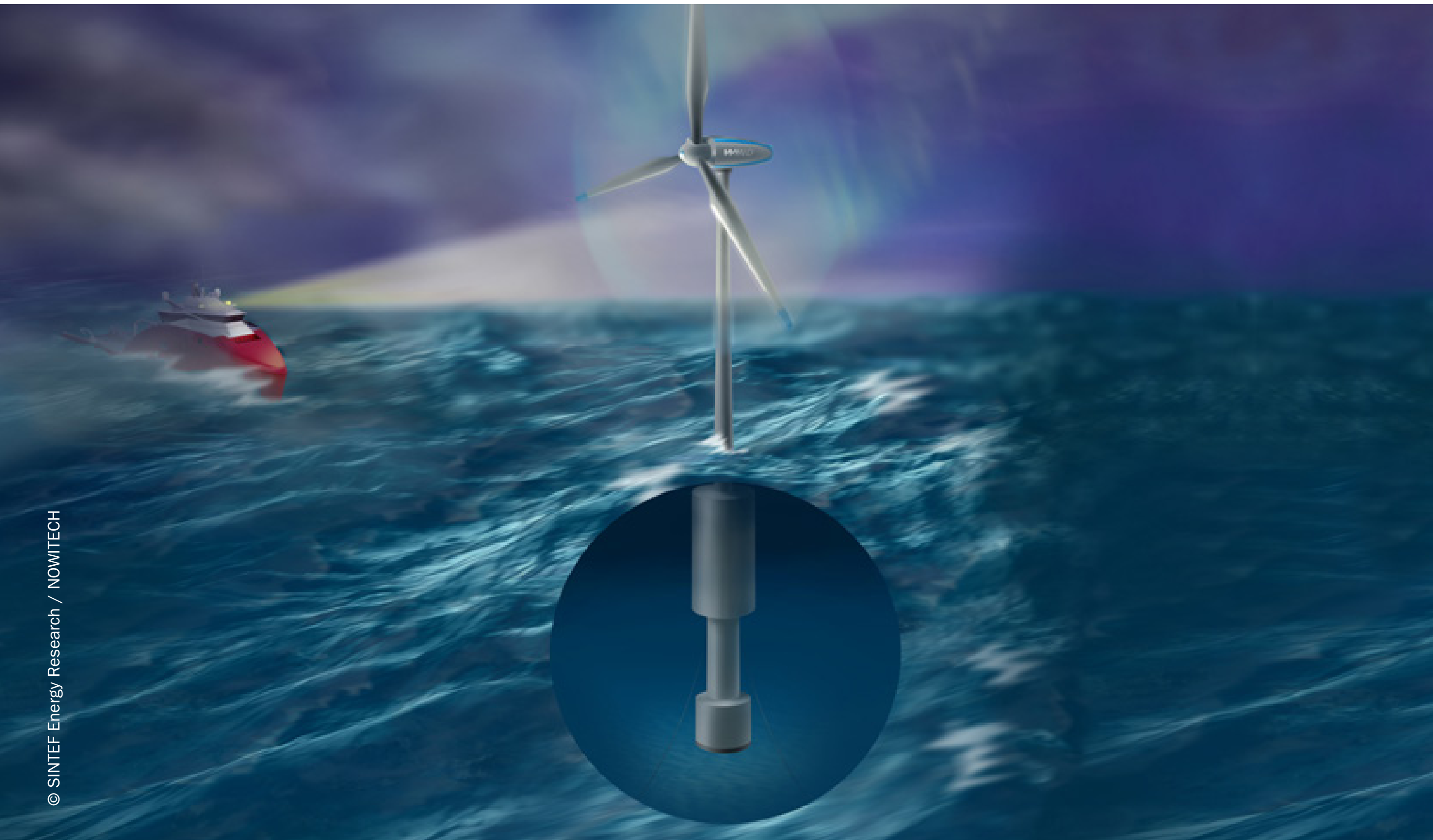
[38] EWEA "The European offshore wind industry - key trends and statistics 2013", January 2014.

TABLE 2 FUTURE BOTTOM-FIXED SUBSTRUCTURE REQUIREMENTS

Type of sub-structure	Extra large (XL) monopiles	Jackets and tripods	Gravity base foundations (GBF)	Self-installing structures: suction buckets	Integrated structures
Challenges	Large diameters >7m or >700t – which will require improved design standards and installation methods	Optimising designs for mass production	Proving installation methods – towing out by tug, or lifting off a barge	Installation of suction buckets in complex soils, and long term performance under cyclic loadings	Transportation of pre-installed turbine and lowering the entire structure onto sea bed

TABLE 3 FLOATING SUBSTRUCTURE DESIGNS

Type of sub-structure	Semi-submersible	Tension-leg platform	Spar buoy
Challenges	Reducing weight of the foundation and optimising for serial manufacture	Mooring and anchoring systems for different soil conditions	Reducing weight of the foundation



In the longer term, if the industry wants to develop wind farms in deeper waters, floating designs will be required. By 2020, the first commercial wind farms using floating concepts are likely to be demonstrated.

In the near term, the major deployment issue is the development of the production facilities and equipment for manufacturing the sub-structures in the necessary quantities at a feasible cost. This will require:

- Significant investment in new manufacturing yards and in the associated supply chain;
- Deployment of new and improved manufacturing processes, procedures and equipment to increase production efficiency – currently challenging because the optimal process depends on the design to be fabricated;
- International standardisation of design and fabrication requirements.

The industry and academia need to acquire data on the behaviour of existing support structures. This information will support research into the development of improved design tools and techniques and better design standards, which can extend the lifetime of structures, reduce costs and develop risk based life cycle approaches for future designs.

From 2020 to 2030, life extension and repowering will become increasingly important as operators seek to maximize the yields from the existing wind power plants. This will require increasingly sophisticated condition monitoring and risk based lifecycle approaches for maintaining the structures, and potentially adoption of new sub-structure designs that are more suited to repowering.

TABLE 4 SUBSTRUCTURES - TARGETS FOR 2020, 2030 AND 2050

	2020	2030	2050
Concept development	**Fixed** • XL monopiles (diameters >7m) commonly deployed • Jackets designed for serial fabrication • Suction buckets commercially deployed • Demonstration of self-installing concrete and steel structures (float out and sink) • New installation methods to reduce & mitigate piling noise **Floating** • Demonstration of spar buoy, TLP (Tension-Leg Platform), semi-sub structures in small commercial wind farms • Improved mooring and anchoring systems	• Fully integrated support structures – from seabed to nacelle – are common • Fixed foundations designed for >25-year life • Self-installing concepts have significant market share • Steel structures optimised for more competitive installation vessel market • Floating cost-competitive with fixed designs in lower depths • Novel designs – Demonstration of floating sub-structures to support novel turbine technologies,	• Novel fixed designs and floating designs
Design standards	• Improved design methods to - Extend **piled structures** into deeper waters - Enable **suction buckets** designs to be used • Allow installation in **challenging soil conditions**	• Methods allow fixed and floating substructures to support 10-20 MW turbines	• 20 MW+ machines, plus novel turbine technologies
Manufacturing	• Improved manufacturing - **Facilities** - **Processes and procedures** - **Technologies** • Increasingly **standardised components**	• Substructures use **standardised components** • **Facilities** exist in Europe to produce hundreds of foundations per year	• Mature market – final assembly in Europe
Operations and lifetime extension	• Improved corrosion protection • Improved condition monitoring to allow risk based maintenance • Optimisation of secondary steel (boat landings, cable protection systems)	• Methods to extend lifetime of substructures beyond 25-years • Lighter, stronger, cheaper materials used extensively	• Sophisticated lifetime extension programmes to increase lifetime to 35+ years
Repowering		First repowering of offshore wind farms	Repowering is common – substructures easy to decommission and to refurbish

6.2.2 Research priorities

The identified research priorities have been grouped under five main areas:

a. Concept development;
b. Design standards;
c. Manufacturing;
d. Operations and lifetime extension;
e. Repowering.

a. Concept development

- Develop, engineer and demonstrate new fixed-bottom substructure concepts, especially suction buckets and integrated structures, for projects in European waters – North Sea, Baltic, Irish Sea and Atlantic (R&D, demonstration);
- Develop, engineer and demonstrate floating designs for deep water developments (R&D, demonstration);
- Provide more opportunities for demonstrating new sub-structure designs (both fixed and floating) through the provision of demonstration sites and support mechanisms to compensate for the additional costs and risks of prototype technology demonstration (demonstration, infrastructure);
- Acquire data on the performance of existing structures to support the development of improved design tools and better standards (demonstration, R&D);
- Develop improved designs to extend the life of substructures, to reduce costs and to incorporate risk based life cycle approaches for future designs (R&D, demonstration);
- Develop new installation methods to reduce or mitigate piling noise (R&D, demonstration).

b. Design standards

- Design standards for fixed foundations – soil interactions, understanding impact of corrosion on lifetime, moving beyond existing soil load-deflection (P-Y) curve and standard material stress-cycle(SN)-curve methods, integrated design of entire structure including dynamic interactions with soil, metocean and turbine; also understanding long term performance of fixed substructures (eg, suction buckets) under cyclic loadings (R&D, demonstration);
- Design standards for floating foundations – integrated modelling, analysis and design of entire structure, including moorings and anchoring (R&D, demonstration);
- Setting appropriate limits for piling noise based on environmental impact and impact on cost of energy (R&D, demonstration).

c. Manufacturing

- Improve manufacturing facilities and set up new ones so that a variety of substructure designs can be built in large numbers at lower cost and with high quality standards (infrastructure);
- New and improved manufacturing processes and procedures, applying the latest technologies in automation, robotics, welding, casting, concreting, corrosion protection etc. in order to increase throughput and to reduce costs (R&D, demonstration, infrastructure);
- Develop standardised and modular components to reduce fabrication costs (R&D, demonstration);
- Develop a competitive supply chain in the medium to long term, with a number of suppliers of substructure components around Europe and fabrication facilities close to Europe's major offshore wind developments – especially North Sea, Baltic, Irish Sea, and Atlantic coast (infrastructure).

d. Operations and lifetime extension

- Develop more effective corrosion protection methods, condition monitoring and risk based maintenance approaches (R&D, demonstration);
- Improve design of secondary steel (eg, boat landings, cable protection systems) (R&D, demonstration).

e. Repowering

- Develop options for end-of-life – both repowering and decommissioning (R&D, demonstration).

6.2.3 Impact

The proposed research and demonstrations will enable reliable design of appropriate sub structures for large offshore wind turbines in deeper waters than today.

Standardisation of components and modular design will facilitate cost effective production, installation and enable mass manufacturing.

Overall, this research topic will lead to a reduction in the LCOE of wind energy and will pave the way for re-powering and de-commissioning.

6.3 Logistics, assembly and decommissioning

6.3.1 Objectives

This section covers the logistics and installation aspects for offshore wind farms and related infrastructural needs, such as installation methods, vessels, tooling, ports infrastructure, marine infrastructure, and accessibility. Logistics and installation are one of the major elements of capital expenditure for construction of offshore wind farms.

The industry began by using existing general purpose vessels that were dedicated mainly to offshore oil and gas works. In an effort to improve construction time and reduce costs of new offshore wind farms, dedicated vessels were then designed. However, latest developments in offshore turbines with larger rotor diameters- and the foundations required for these turbines- are already constraining or exceeding even the newest vessel designs and current port infrastructures. The cost reduction target that the industry is obliged to achieve drives the need to intensify efforts to improve all aspects of safety, logistics and installation.

The targets for 2020, 2030 and 2050 are illustrated in the table below:

6.3.2 Research Priorities

The R&D topics identified have been grouped into four main areas:

a. Logistics;
b. Infrastructure;
c. Assembly onsite;
d. Decommissioning;

a. Logistics

- Develop new logistic planning tools for optimised installation and maintenance, including vessel and staff management. This includes methodologies and software specifically developed for offshore wind farm construction and maintenance;
- Design and construction of new methods and means (vessels and tools) to allow routine installation of large scale wind farms. Projects can involve Dynamic Positioning (DP) vessels with large capacity for foundation and wind turbine installation and features for the wind turbine components that enable installation from the floating DP vessel;
- Develop new foundation structures, both fixed and floating, to reduce installation and logistic costs by specifying the design;
- Develop methods to improve transport of components to a logistic hub, optimising processes by using the most suitable vessels and transport (standard vs. specialised, long- vs. short distance transportation). New tools and vessel designs (adapting existing vessels or providing new ones) are included in this.

TABLE 5 LOGISTICS, ASSEMBLY AND DECOMMISSIONING - TARGETS FOR 2020, 2030 AND 2050

2020	2030	2050
Achieve serial large scale implementation of offshore wind with known technologies. Achieve cost reductions by improving current methods	Achieve cost reductions by implementing new logistics and installation methods, infrastructures and products (wind turbines, foundations and electrical infrastructures)	Dedicated OW technologies and improvements to further simplify offshore logistics and installations by extensive onshore fabrication and fast offshore installation, almost independent of weather

b. Infrastructure

- Design and construct dedicated offshore logistic hubs. Projects can cover novel optimized hub designs on the coast or new long term projects such as islands and floating facilities. Develop dedicated port facilities for assembling and/or manufacturing key offshore wind components (e.g. blades, nacelles, towers, foundation substructures) in order to improve supply and reduce transport and construction costs.

c. Assembly on site (installation)

- Design and construction of specific techniques and tools for safe offshore installations rather than upgrading onshore techniques;
- Develop new methods to mitigate installation noise with alternative tools that do not affect the installation schedule or add to installation costs (e.g. vibratory pile driving, drilling of piles and alternatives);
- Develop new foundation and turbine designs that allow assembling and commissioning complete system in sheltered waters, dock or even on land, and easy transport to final offshore site;
- Develop access systems from service-, installation-, commissioning vessels to turbines for a broad range of wave heights (Hs).

d. Decommissioning

- Develop methods to decommission equipment offshore, turbines, substructures and cables along with repowering and/or life extension of wind farms.

Issues related to the harmonization of legislation are addressed in the section on Market Deployment (page 62).

6.3.3 Impact

The above research priorities will greatly improve the logistics of planning of large wind farms, develop the infrastructure of ports and lead to shorter installation and maintenance time. The activities focused on safety, logistics and installation as outlined above will pave the way for cost reductions by simplifying the offshore installation process and provide greatly increased access.

6.4 Electrical infrastructure

6.4.1 Objectives

Experience with offshore conventional wind farm collection systems and export / grid connection systems has highlighted challenges related to cable costs, cable installation, size and weight of transformers, size and weight and costs of offshore HVDC platforms and significant electrical losses. These problems can be solved to some extent by improving current technologies, but innovative solutions are needed to achieve further cost savings on electrical infrastructure, reduction of electrical losses and more compact and lightweight components. The interoperability of HVDC converters by different manufacturers is yet to be demonstrated, and the potential for large offshore wind farms and converter stations for providing system services is still not fully developed. The use of power electronics in wind turbines as well as in other applications is advanced, but can be further developed to enhance its reliability and to provide alternative wind farm electrical infrastructure solutions, such as DC collection systems.

The development of an offshore transmission grid, including its planning and operation tools, is a critical element in the successful large scale deployment of offshore wind farms. Challenges include technical, market and regulatory issues. Studies indicate that significant savings can be achieved at European level by overall system optimisation compared to suboptimal solutions for connecting individual wind farms. The future large scale offshore generation will influence the overall European power system operation. Offshore energy storage may help to improve balancing capabilities and allow greater use of the offshore grid capacity.

TABLE 6 ELECTRICAL INFRASTRUCTURE TARGETS FOR 2020, 2030 AND 2050

2020	2030	2050
• AC collection systems inside wind farms are built to operate at 66 kV • Medium voltage DC solutions are demonstrated for wind farm collection grids • Improved submarine cable designs, installation methods and protection system are commercially available • Submerged solutions for substations and reactive power compensation are demonstrated • Higher voltage intra-array cabling to reduce transmission losses • Dynamic cables for floating foundations are developed and commercially available from more manufacturers • Efficient and reliable transmission technology is deployed for connecting far offshore wind farms	• A larger capacity offshore grid is available between northern European countries and offshore wind farms • A multi-terminal HVDC grid is being built • Inter-array DC collection systems are commercially available • The offshore grids and wind farms provide enhanced system services employing wind turbine converters and HVDC stations as virtual synchronous machines, possibly combined with some offshore energy storage	• A meshed offshore grid is fully implemented in northern and southern Europe with offshore wind farms together providing for full system services, contributing to reliable and secure operation of the power system with high amounts of renewable generation

6.4.2 Research Priorities

Three research priorities have been identified:

a. Innovative wind farm collection grids for offshore applications;
b. Optimisation of the offshore grid infrastructure;
c. Enhanced system services from offshore wind farms.

a. Innovative wind farm collection grids for offshore applications

The objective is to bring major innovation to the design of the wind farm collection grids for offshore applications. Alternative solutions should include those that may reduce the complexity of wind turbines and enable more compact and lightweight sub-stations to connect to the HV transmission system, e.g. DC collection grids. Cables and the connection to the transmission system should also be assessed, including clustering of wind farms and their connection to multi-terminal HVDC systems. Wind farm cost savings - from the reduced complexity of wind turbine electrical system, efficiency, reliability, controllability, protection and fault handling - should be verified through analysis, numerical simulations, lab tests and demonstration projects.

b. Optimisation of the offshore grid infrastructure

The objective is to prepare for an optimised offshore grid infrastructure for connecting offshore wind farms. The work should target development of more compact and lightweight offshore substations, both HVAC and in particular HVDC, also ensuring interoperability of HVDC stations between different manufacturers. Improved planning tools and studies should address power system operation and stability and market and regulatory issues allowing for overall system optimisation for connecting offshore wind farms interlinked in a future meshed offshore grid.

c. Enhanced system services from offshore wind farms

The objective is to provide for enhanced system services from offshore wind farms, in particular improved inertia and balancing capabilities. Solutions and technologies should be developed for wind farms and HVDC converters to operate as virtual synchronous machines providing system inertia, possibly combined with offshore energy storage for improved balancing capabilities. System feasibility, benefits and cost savings can be assessed through analysis, numerical simulations, lab-scale tests and demonstration projects.

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6.4.3 Impact

The research in this area is crucial for successful large scale deployment of offshore wind farms and enables them to provide reliable and secure operation with high amounts of renewable power penetration. There can be significant cost savings due to the reduced complexity of the wind turbine electrical system, increased efficiency, reliability, controllability, protection and fault handling.

6.5 Wind turbines and farms

6.5.1 Objectives

The economics of offshore wind energy favours multi-MW machines installed in large wind farms. The offshore environment may enable the development of turbines with fewer design constraints, for example in terms of aesthetics and operating noise level. However, addressing marine conditions, installation noise, wakes in wind farms, corrosion and reliability issues creates new challenges, which lead to design modifications from an onshore machine in the near term and to the development of specific offshore designs in the medium and long term. The key factors affecting the deployment of offshore wind farms are the shortage of turbines, their reliability and the costs for electrical infrastructure, foundations and installation.

The targets for 2020, 2030 and 2050 are illustrated in the table below:

TABLE 7 WIND TURBINES AND FARMS – TARGETS FOR 2020, 2030 AND 2050

2020	2030	2050
• Offshore specific wind turbine design • 8-10 MW offshore wind turbines commercially available • Large scale manufacturing of wind turbines • Offshore test facilities must be developed to ensure turbines are properly tested for higher reliability • Improved validated wakes models and better understanding of offshore meteorology conditions • Wind farm layout optimisation by integrating met-ocean, soil data, wake models and foundation types	• Lifetime costs competitive to conventional sources of energy • Safety offshore to be quantified to higher levels than onshore • Large scale commercialisation of 10 MW range wind turbines	• Commercial large scale floating wind farms • Innovative wind turbine designs commercialised

6.5.2 Research Priorities

Five research priorities have been identified:

a. Development of test facilities to validate new offshore wind turbines (infrastructure);
b. Validated design and simulation: innovative offshore wind turbine design, performance simulation should be verified in an offshore environment (marine conditions) to minimise uncertainties;
c. Measure and analyse the external climate, environmental design parameters, wake effects and demonstrate opportunities to improve layouts, increase energy yield, reliability and reduce costs;
d. Innovative offshore technology and improved reliability: new integrated turbine and sub structure technologies, combined with a better understanding of wake effects, should minimize machine wear and tear and increase reliability, while reducing the cost of energy;
e. Loads reduction, lower maintenance costs and increased performance through advanced wind farm control.

6.5.3 Impact

The research activities will improve performance of new offshore wind turbines, increase large wind farm efficiency and minimize uncertainties in wind turbine operation. The activities outlined above are a pre-requisite for large scale offshore wind farm commercialisation and economically sustainable power production.

6.6 Operations and maintenance

6.6.1 Objectives

Operations and maintenance (O&M) strategies, which maximise the energy yield while minimising O&M costs, are essential for cost competitiveness of offshore wind energy. The achievement of the above targets requires the development of sophisticated O&M strategies, concepts and support tools. These tools should address advanced condition and risk based maintenance philosophies as well as remote and non-intrusive maintenance. The coordination and dispatching of offshore O&M services and logistics will benefit from novel software and operations research that can assist O&M managers in the deciding how, when and with which equipment O&M missions will be most successful. Effective O&M is also dependant on the availability of optimised service vessels and access systems.

The 2020, 2030 and 2050 targets are listed in the table below:

TABLE 8 OPERATION AND MAINTENANCE – TARGETS FOR 2020, 2030 AND 2050

2020	2030	2050
• Enabling easy and safe access for maintenance and service works on wind turbines under a broad range of relevant site and sea conditions • Shareable failure database for modelling the reliability behaviour and benchmarking • Implementation of a standardised reference system for components, failures and measures for offshore wind turbines • Introduction of condition and risk based maintenance systems	• Reliability characteristics for key components used for load dependent O&M strategies and concepts • O&M strategy will include experience based decision support methods for optimizing service routines • Reduction of planned maintenance visits by 50% through probabilistic planning methods	• Technologies and procedures that lead energy based availability of 100%. Technologies and procedures that minimize unplanned maintenance. Planned maintenance will be scheduled in low wind periods to minimize production losses and thus maximize energy yield

6.6.2 Research priorities

Three main research priorities have identified:

a. Versatile service fleets and safe access
b. Improving reliability and availability
c. Asset management

a. Versatile service fleets and safe access

One important step is the general availability of a fleet of various tailor made vessels and transfer systems for the offshore wind industry. This requires the development, construction and certification of new vessel and transport systems for a broad range of tasks. These will range from helicopters, to an array of different vessels, including jack-ups capable of lifting the heaviest components into and out of the nacelle. The systems must enable offshore work, e.g. the lifting of components as well as safe and easy access to and from the wind turbines, meeting health and security standards. Short term research should to focus on improving the presently limited options for accessing offshore facilities in a broad range of marine and site specific conditions.

b. Improving reliability and availability

In order to improve O&M services for offshore wind turbines, statistical analyses of operation and maintenance data will be essential. The introduction of a standardised reference system for components, failures, service measures and so on will play an important role in improving reliability and availability. Operational and failure data from offshore wind projects will enable the development and verification of new O&M strategies and concepts. Probabilistic planning of maintenance based on measured data from selected turbines of a wind farm needs to be developed. Research programmes should improve operational efficiency and reduce costs.

In the mid-term (up to 2030) further progress in O&M tools should have been achieved, mostly in terms of software and more resilient, optimised components. Advanced O&M tools will enable load dependant strategies for individual turbines, based on load or stress levels induced by wakes and waves. Ideal service slots and working schedules will be calculated through the evaluation of data on each component, fittings, vessels and service staff. Moreover, highly reliable weather forecast will be used to improve the analysis. Detailed and inter-coordinated operation lists, work permits including options and alternatives to prevent unplanned machine idling time will be ready to be implemented. The achievements of these targets can make a significant contribution to drive down O&M costs.

In the longer term (by 2050), the development of systems to reduce human intervention will be the major area of research. This can be achieved by designing turbines with remote functionality and redundancy. It will involve reducing scheduled maintenance efforts through monitoring systems, which will reduce the need for scheduled local checks.

c. Asset Management

In the coming decades thousands of wind turbines will be operating in European waters. These turbines need to be maintained and serviced. Service and maintenance requirements will vary between individual projects, depending on the specific site conditions. Research of full life cycle cost models under specific site and asset conditions, e.g. near or far offshore distances, service concepts etc., can contribute significantly to reducing wind energy costs. One of the key challenges will be to compare the overall cost of investing in components with high reliability and low O&M costs, versus choosing cheaper components with higher expected O&M costs over the turbine's lifetime.

6.6.3 Impact

The impact of the overall O&M research strategy is to minimise unplanned maintenance and to standardise planned maintenance activities so as to maximise the energy yield while reducing the costs of operation and maintenance.

6.7 External conditions

6.7.1 Objectives

Offshore wind turbines are designed for site specific conditions to minimise cost of energy. These include not only meteorological and oceanic conditions, but also seabed properties (soil and bedrock), sediment transport and icing. Since wind farms span large areas in different seas across Europe and with varying water depths, access to site specific design information requires a focused and diverse measurement programme with shared database storage.

Installation of offshore foundation is a source of underwater noise that has impact on fish and marine mammals. At present this is regulated through authorities' requirements, that differ widely from country to country. A coordinated scientific effort to establish a sound basis for the protection of fish and marine mammals can allow authorities to issue regulations that help the industry to mitigate installation noise.

The targets for 2020, 2030 and 2050 are listed in the table below.

6.7.2 Research Priorities

Four research priorities have been identified:

a. Soil conditions;
b. Met-ocean conditions;
c. Spatial planning;
d. Environmental aspects.

a. Soil Conditions

The soil is multi layered and can include different components such as clay, sand, gravel etc., which requires geotechnical surveys. At potential locations for wind farms, measurement of soil properties must be carried out. This requires ad-hoc instruments on site and further laboratory analysis of soil samples. Some of the relevant soil parameters for wind turbine design are stiffness, strength and damping, which are to be accurately estimated from measurements. Furthermore, the variation of these properties with time and distance needs to be estimated based on the standard deviations identified in the measurements. A database of measurements collected from various

TABLE 9 EXTERNAL CONDITIONS - TARGETS FOR 2020, 2030 AND 2050

2020	2030	2050
• European data set repository (design atlas) – soil, sediment transport, met-ocean conditions • Met-ocean measurements that provide improved short term forecasting (three days) for power production, installation and maintenance visits • Floating wind and wave measurement bankable for resource assessment • Cost efficient geotechnical test methods for foundation design and cabling • Atmospheric conditions including turbulence measurements at heights of 120m-250m	• European level power forecasting based on collective met mast and other measurements • Soil condition measurements and geo-physic survey through non-intrusive methods	• Quantify effect of offshore wind farms on the local climate • Synergistic use of wind platforms with aquaculture and other multipurpose floating platforms

locations off the European coastline up to a depth of 50m is required to reduce the uncertainties in the design of wind turbine support structures and quantify the risks in the preliminary design phase.

It is vital to challenge the current practice of site investigation methods comprising in-situ investigation in conjunction with sample boreholes, where the samples are taken to onshore laboratory facilities for further testing. A development towards in-situ only investigations combined with new foundation design methods may reduce cost, time and risks for future foundations.

b. Met-ocean conditions

Meteorological measurements and investigations offshore are required for accurate estimation of wind turbine design loads and power performance. The meteorological information is to be based on measurement of wind speeds, turbulence over a multi-year period and assessment of air-sea interaction, including roughness of the sea. The Met-ocean analysis must provide the designer with accurate joint probability distributions of the wind speed/ wave height correlations, as well as an accurate estimate of extreme wind/wave occurrences. The conditions for normal, extreme and severe sea conditions applicable to offshore wind turbine design must be estimated at all water depths for potential wind turbine installations, not only for fixed support structures but also for floating support structures. Spectral predictions of the wave height need to be made to better predict design loads on wind turbine foundations and help quantify uncertainties on loads during the design phase. More focus is needed on atmospheric flow conditions at turbine rotor heights stretching from 100m to 200m above mean sea level as well as on the complex flow conditions near coastal areas. Measurement equipment for such an extensive assessment programme includes floating meteorological masts combined with wave buoys, floating lidars, satellite based wave height estimation and ship based measurements. In the medium term, methods such as unmanned aerial vehicles, radars, can be implemented to measure wake conditions in wind farms, as well as the change in meteorological conditions over wind farms. Such a repository of wind and wake data must also aid short term energy forecasts from wind farms across Europe.

c. Spatial planning

Spatial planning tools for wind farms, inclusive of environmental considerations, are required. Since offshore wind farms are located in marine environments, they can disturb the natural habitats of fish, maritime mammals and birds and delay the growth of other industries such as aquaculture and shipping. Turbine installation noise needs to be mitigated and continuously monitored so as to not affect marine life. Environment protection legislation affects the wind energy industry and therefore, targets for minimising environmental impacts are required. Targets on mitigation of installation noise are needed in the near term to support the fishing industry. Large offshore wind farms can also interfere with oil and gas exploration and drilling. Spatial planning of offshore wind farms may need to take into account the needs of the oil and gas industry and also avoid potential collisions with shipping routes. Information about potential marine zones shared between offshore wind farms, shipping and oil and gas during the planning phase of the wind farm layout, can provide a safer environment for power production.

d. Environmental factors

Multi-purpose wind farms combining environmental factors with energy production are required, such as with aquaculture, desalination units etc. In the medium to long term, as wind farms grow in size and utilise larger parts of the sea in northern Europe, their long term impact on the regional climate and marine environment needs to be investigated.

6.7.3 Impact

The above research priorities will significantly reduce the environmental uncertainties in offshore wind turbine design, and reduce wind turbine cost by providing site specific design calibration based on acquired soil, met-ocean and spatial planning data. In the long term, it will also lead to effective harmonisation of the wind farm system with the natural environment and other maritime activities.

7 MARKET DEPLOYMENT STRATEGY

Wind energy has been developed in record time, taking a growing share in the energy mix. The entire sector, from the manufacturers to the utilities has proven to be flexible in a market that has required the highest standards, not just on the technical side but also from environmental, social and finance perspectives. In this time, a new method of harnessing wind energy has emerged. Offshore has just taken its first steps in the energy market, but considering the success of onshore wind, a brilliant future could lie ahead. However, the current market design is not fit for optimal integration of a large share of renewables and this need to be addressed.

The electricity sector is complex and for decision makers need to juggle quick solutions for current problems with long term policies that will determine the continent's future energy mix. An even handed approach to all energy technologies will aid understanding of the real cost of energy in the European economy and provide decision makers with a perspective that places wind a leading position in the electricity mix.

The development of efficient market structures will reduce intermediate costs and lead to lower energy costs, while maintaining the highest standards in development, construction, operation and maintenance, and decommissioning.

This chapter examines six topics necessary to enhance the deployment of the wind energy market:

1. Enabling market deployment;
2. Adapting policies;
3. Optimising administrative procedures;
4. Integrating wind to the natural environment;
5. Ensuring public acceptance of wind power;
6. Human resources.

7.1 Enabling market deployment

7.1.1 Enabling smart market deployment of wind in a transitional world

The current world economic system is in turmoil[39] causing everything to be questioned and creating concerns and uncertainty about the future and about investment decisions. This uncertainty also affects the energy sector.

Power generation has developed in the same way in most of the industrialised world. Electrical utilities were originally developed as a state owned/franchised or as regional co-operatives. These models have been replaced in most cases with a semi free market model with different forms of support[40].

In the case of wind power we now have the opportunity to scientifically examine its pros and cons in comparison with conventional power generation plants. Wind has been subjected to a rigorous impact examination, as it is a new industry with high standards of impact assessment. The support given to wind is only on the tariff; while other sectors receive additional support in different parts of their operational chain[41] (extraction, refining, logistics, installation, etc).

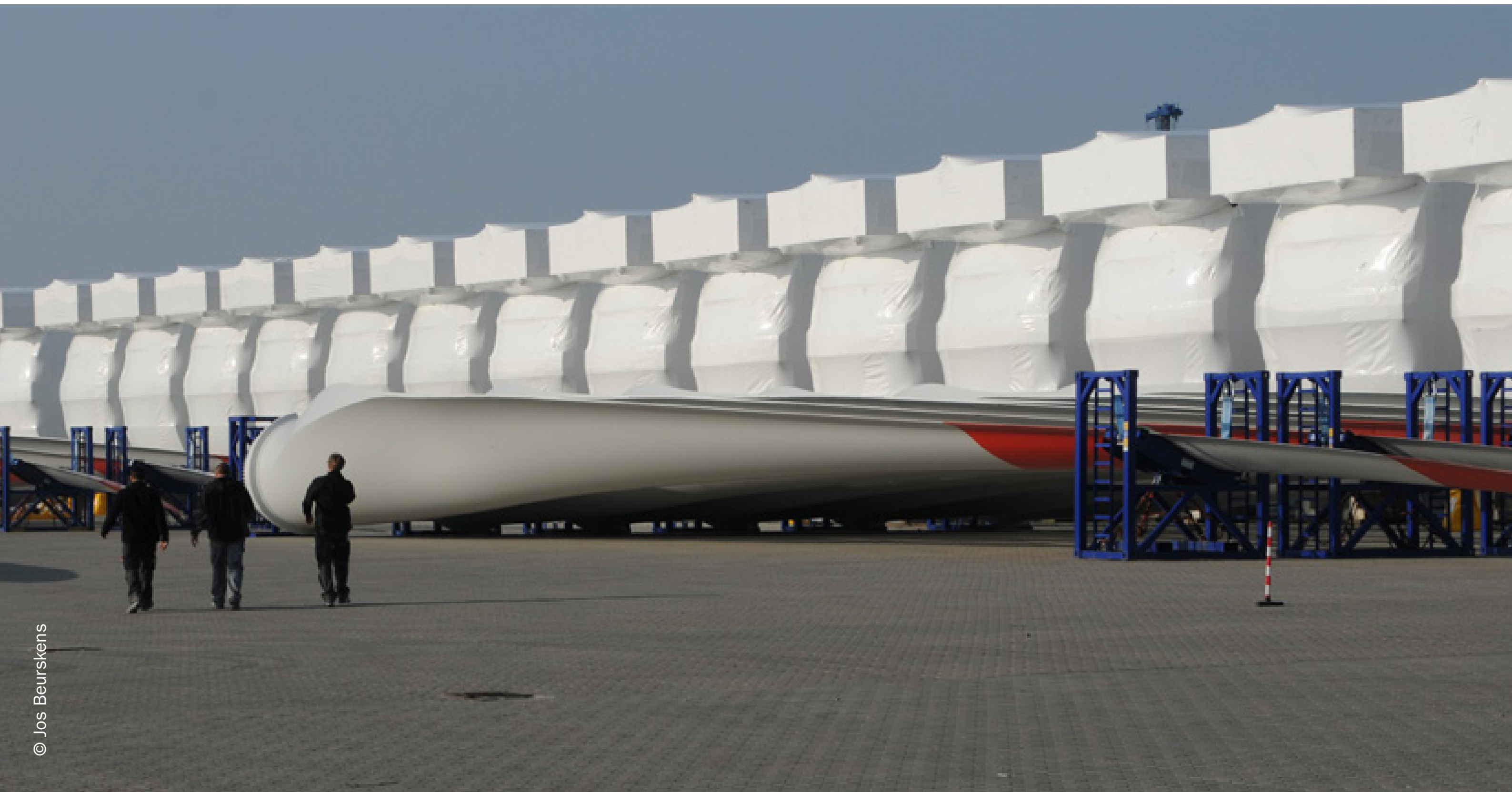
To encourage a level playing field in the evaluation of different power generating technologies we need to approach investment decisions in a different way. Building a power plant using a particular technology is a long term decision, which can be expensive or impossible to reverse. Consequently, the long term, cumulative impacts of the chosen power technology have to be taken into account.

A study to lead to a SSEE (Scientific, Strategic, Environment and Economic) analysis of wind power generation versus other generation technologies could clarify which generation mixes are appropriate to invest in and why.

Scientific, strategic, environmental and economic aspects have been investigated separately, causing confusion and depriving policy makers and investors of a comprehensive overview. Some work has been done to determine the actual state of play, but this is uncoordinated and lacks a holistic perspective on the generation sector.

We now have the opportunity to develop a new SSEE model, providing a sophisticated method for managing power generation planning and investments and illustrating the real contribution that wind power generation can make.

39 http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html
40 Energy subsidy reform: Lessons and implications January 28, 2013, International Monetary Fund.
41 http://www.worldenergyoutlook.org/resources/energysubsidies/



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7.1.2 Power generation investments

We need to build a new model for the evaluation of wind energy vis-à-vis conventional energy technologies to assess the current and future impacts of different technologies.

Europe could then pioneer a better way of evaluating energy investments and illustrate clearly which power generation technologies would guarantee a safe, secure, sustainable and environmentally friendly energy supply.

SSEE analysis of different power generation sources in terms of their entire life cycle should lead to a score taking into account the following variables:

- Construction: environmental cost of construction and processing of raw materials;
- Fuel extraction and processing: environmental cost of dust, heavy metals, water usage and contamination and other impacts;
- Benefits to the local economy at the installation areas (economy, employment, etc.) and at a national level creating an industrial sector;
- Amount of pollutants a given energy technology produces, local impact on heritage, flora, fauna and human health;
- Impact on environment, landscape and water resources (by use or contamination) due to power generation;
- Balancing costs associated with grid integration;
- Vulnerability of the technology to fuel disruption, pricing and supply uncertainties;
- Risk and dimension of possible accidents (footprint);
- Direct and indirect support: tax breaks, externalisation of services, accelerated depreciation, etc.
- Decommissioning costs, restoration of the site, and recycling options;
- Future cost of investment decisions: waste storage, climate impact, etc.

Sorting this out for every energy source would enable each technology to be judged on its merits.

The time has come to carefully assess which power generation technologies are needed for the future. The SSEE study can help politicians to decide which generation mix to invest in.

7.1.3 Optimising energy market policy

Wind power is a maturing technology that is getting closer to market competitiveness. However, the current market model is not providing sufficient security to investments in renewable energy technologies, including wind, unless investors are supported through support mechanisms. This is partly caused by the Emission Trading Scheme (ETS) failing to maintain stable and sufficiently high carbon prices, but also by significant subsidies in non-renewable energy sectors and the current structure of the power market, which does not have a system approach. This has created a confusing market that does not provide accurate information on the real cost of energy – including all internal and external costs.

Optimisation of energy market policy should therefore respond to the challenges posed by the growing share of renewables. The discussion has been initiated by the European's Commission green paper 2030[42], dedicated to understanding the stakeholders' view on shaping energy market policies post 2020. A series of measures will be taken to clarify the future of the electricity market, which will lead to flexibility and faster wind integration.

Gradual elimination of direct and hidden subsidies for various mature energy sources (both conventional and renewable), taking into account the total life cycle cost of energy sources and technologies, along with creating a strong CO_2 price signal would lead to a level playing field for all energy technologies. It would also promote clean energy sources, such as wind. Development of new wind capacity should not be driven by the level of subsidy, but by the resource potential.

Integration of the European energy market, which would facilitate wind integration, needs to be supported by a number of measures. Physical grid strengthening and construction of interconnections is a prerequisite to integration with the added value of the grid security. The ongoing process of market coupling helps to better use cross-border capacity, provide market based price signals for investments in cross-border capacity and capitalise on investments in flexible generation. Well-functioning intra-day cross-border trading will increase

[42] Brussels, 27.3.2013 COM(2013) 169, GREEN PAPER: A 2030 framework for climate and energy policies.

options for generators to balance portfolios by taking advantage of interconnected traded power markets. Extra attention needs to be directed at the unification of market rules for forecasting power production, reactive power balancing and grid management. Enabling demand management and low cost storage options to participate in day-ahead and within-day markets, as well as market-based schemes for flexible capacity and reserves would ensure an optimal energy mix, thus stabilising prices and ensuring security of supply. It is estimated that savings related to cross-border coordination and optimal use of resources could amount to €426bn in the 2020-2030 timeframe, in comparison to a planned decarbonisation of the power sector in non-coordinated, fragmented efforts in national markets[43].

7.1.3.1 Research priorities:

- Policy measures driving faster European energy market integration;
- Impact of all subsidies (direct and hidden) on the cost of energy in Europe and approaches to gradual elimination of support for mature and maturing technologies. As previously stated, the levelised-cost study should give a complete picture of the impacts and benefits of every energy source on the electrical market, and the social and financial environment. Clearly, this can be done only when all externalities of conventional technologies are taken into account (e.g. pollution, volatility of fuel costs, environmental and health hazards and so on);
- Optimisation of ancillary services and reform of day-ahead and intraday markets for flexible capacity, Demand Side Management (DSM) and storage options, including cross-border and regional markets;
- Identification and development of low cost energy storage opportunities that may help to add flexibility to the operation of the electrical system;
- Definition of the reserve capacity in Europe for 2020-2030 and 2030-2040, to plan infrastructure development and secure financing mechanisms;
- Develop market rules promoting flexibility and a broad range of ancillary services to accommodate higher shares of wind power.

These measures will improve the long term competitiveness of Europe.

7.1.4 Improving grid infrastructure

Along with growing penetration of renewable energy in Europe, there is a need for investments to strengthen the infrastructure to optimise the use of wind resources, decrease wind cost, link the areas with the biggest potential (North and Baltic Seas and Iberian Peninsula) to consumption centres and facilitate faster energy market integration, as well as the creation of an integrated European energy system.

Greater wind integration should include a higher degree of network monitoring and automation, interconnectors, demand response and energy storage available for network operators and utilities.

Flexibility over the grid performance could be achieved by many different ways, taking account of the potential in each country and region for economies of scale. Distributed sources of energy such as biomass, hydro power with storage capacity, and gas can contribute to the penetration of renewable energy improving the flexibility of the supply combined with rapid grid control.

Development of smart electricity- and gas networks will result in:

1. Better coordination between control areas;
2. Regional integration;
3. Improved strategies for system operation;
4. Regional resource- and grid planning;.
5. Integrating wind power generation into the European system planning strategies.

While taking into account the within-day variability and uncertainty resulting from the forecast of higher levels of renewable energy, all these measures will decrease the need for new flexible capacity in the areas where energy balance (between generation and consumption) is required and thus limit the costs of reserve ancillary services.

Europe's transmission system operators (ENTSO-E) have an ambitious network development plan to increase transmission lines capacity by 64 GW by 2020, which is a 30% capacity increase in comparison to 2010 .

[43] European Climate Change Foundation, Roadmap 2050, Power Perspectives 2030 In the road to a decarbonised power sector.
[44] https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2012/

Additional investments in transmission grids, including off-shore wind connections totalling €68 billion are planned from 2020 to 2030 and will facilitate the construction of another 109 GW of transmission capacity. These investments need to be coordinated across the EU. R&D grid integration projects, such as Twenties[45] or Connecting Europe Facility[46], are being developed so that existing grids are optimized and improved algorithms in capacity calculation are implemented.

Unification of market rules for grid management and participation to ancillary services are an important consideration. Investment in the development of accurate forecasts and in the communication systems at the wind farm level, but also with the TSOs/DSOs control centre, should be carefully considered and planned. Efforts will be needed from the grid side and the wind developers' side.

Moreover, stable investment conditions are needed to encourage grid operators to contribute to the growth of the integrated system. Today's tariffs are still defined at national level, which does not always ensure the required rate of return for innovative cross border projects that could benefit the entire region.

Such a modern grid should also be supported by continuous improvements of wind turbine technology, so that it becomes more predictable and grid friendly.

7.1.4.1 Research priorities:

- Foster international interconnections to allow a real European grid;
- Coordination of regional grid developments;
- High-voltage (HVDC) long distance and new energy storage technologies that can accommodate growing shares of wind and easily transport the energy produced in generation areas (such as the north of Europe and Spain) to consumption districts;
- Methodologies to encourage system operators to invest in interconnectors and expand regional integrated networks efficiently;
- Improved grid management and application of smart solutions allowing for better communication with variable sources and full exploitation of cost- effective resource potential, including storage and DSM;
- Improve communication protocols and systems for wind forecasting and wind farm control in individual wind farms and wind farm control centres, to provide ancillary services to the grid;
- Increasing grid-interaction features in wind turbines.

45 http://www.twenties-project.eu/node/1
46 http://ec.europa.eu/energy/mff/facility/doc/2012/connecting-europe.pdf

7.1.5 Cost Reduction

Both onshore and offshore wind energy continue to attract significant investment. Indeed, it is worthwhile noting that in 2010-11, wind power dominated the utility scale asset finance sector, with €70bn invested in projects, a 33% increase on 2009 (Bloomberg New Energy Finance). This figure was significantly affected by the volume of new build activity in the UK (via Round 2), mainland Europe, China and Brazil. However, over this period, there was a significant reduction in the flow of private equity and venture capital into the wind sector. The reasons for this are numerous but are dominated by a number of key factors:

- Challenges in developing and operating offshore wind power plants;
- The extrapolation of onshore asset performance data to offshore environments and all of the associated uncertainties;
- The availability of performance data for offshore wind assets from which key performance indicators for the finance sector can be constructed;
- The level of risk – both perceived and real – for the finance and insurance sector on operations and maintenance of complex offshore wind farms and their ancillaries (wind turbine O&M, spares, grid connection, cables, power electronics, etc.);
- Optimisation of O&M services in the onshore sites;
- Grid codes harmonisation among the different EU members and utilities;
- A lack of consistency of energy policies across the countries engaged in the roll-out of offshore wind farms;
- No standardisation of the key technologies and components underpinning the offshore wind sector;
- Barriers to innovation in the offshore wind supply chain due, to a combination of the above factors.

7.1.5.1 Offshore wind system

For these reasons, a significant level of uncertainty applies to capital intensive, nascent , offshore wind energy industry. Such uncertainty has a huge impact on the LCOE through the risk premiums assigned to both the cost of capital and cost of insurance. Moreover, the lack of standardisation and volume production of key wind turbine generator system components (and, as a result, inflated unit costs) means that inefficient supply chains continue to contribute to the higher costs of the offshore wind sector.

However, as the offshore wind industry develops, it will be essential to monitor new cost factors that become relevant. Logistical planning of operations and maintenance activities, performance optimisation of assets to maximise output from wind turbine generator systems, spatial planning and optimise control strategies to minimise the adverse effects of turbulent wake interaction and cable management to ensure efficient power export, will all drive down the cost of offshore wind energy. With the introduction of new technologies or working practices, the LCOE may increase in the short-term until new approaches become embedded. This should be recognised and accounted for in any cost reduction research based activity.

In view of the above, the main focus should be on:

a. Asset classes

A wind turbine system comprises a number of subsystems (asset classes). Each asset class has its own risk profile that needs to be understood. Typical parameters defining this profile are mean time to failure (MTTF) and mean time to repair (MTTR). These directly affect energy production and the commercial viability of the associated wind farm, both of which have a direct impact on the LCOE. Therefore the management of MTTF and MTTR should be a key focus of research programmes in O&M.

b. Asset performance data

The concerns of the finance and insurance sectors should be addressed. This should include the development of asset performance databases for offshore wind assets, covering testing facilities and operational sites. Existing European sites should be approached to provide data for a common ‘EU data management and offshore wind informatics’ platform. The latter could be used to produce the correlation coefficients used in the finance industry’s cost of capital models. As more data becomes available, reliability models of certain asset classes (blades, drive trains, towers, power electronics, cables, etc.) can be built and used as the basis for pricing risk of offshore wind turbine generator systems. Involving the finance and insurance communities in this process is essential, to increase confidence and reduce the risk, and therefore the cost, of investments.

Data management and energy IT processes are a key means of driving down the cost of offshore renewable energy systems. This should include information and communication technologies (ICT) architectures, data management algorithms (including the use of adaptive systems), encryption tools and mathematical models for risk and reliability. Reducing the cost of offshore renewable energy systems will require a smart asset management approach, underpinned by appropriate ICT systems. This is also applicable to onshore wind.

c. Standardisation and standards

Strong support for innovation in standards and component standardisation must be provided. Testing, experimental design and performance reporting programmes will be essential. Once testing has been concluded, standardisation of component design can be achieved, standards can be developed and supply chains created to produce components in sufficient volumes to generate economies of scale, directly impacting asset build costs and the LCOE. Once this has been achieved, market confidence will grow with the maturing of the industry.

d. Operations and maintenance (O&M)

The operation and maintenance of complex offshore wind farm structures in far-from-shore, harsh environments remains a significant issue. This challenge is also shared in other harsh operating environments such as those with extreme temperatures, high altitudes, as well as hurricane and desert conditions. The sheer size and scale of the challenge necessitates research and innovation.

There are numerous challenges relating to transportation, supply chain logistics, construction, site management, scheduled and non-scheduled maintenance, emergency repairs, weather windows, personnel transfer and ocean stakeholder interaction. Health and safety is of paramount importance. Optimising O&M logistics will lead to a significant reduction in operating costs (OPEX); optimising construction costs will lead to a material reduction in CAPEX, as well as making a difference to OPEX through improved lifecycle costing.

e. Techno-economic decision making tools

As cost reductions start to affect the LCOE, the principal data sets driving them will become more apparent. It will be important to capture these effects to allow future scenario modelling to be undertaken. The development of techno-economic models that reflect the expected evolution of an offshore project, will represent a major step forward for the offshore wind industry and will increase the propensity for data to be shared across the sector.

7.1.5.2 Onshore wind

In addressing the needs of the offshore wind sector, the onshore wind sector must not be overlooked. There is an opportunity to optimise onshore wind turbine asset performance, as well as innovate in operations and maintenance, re-powering of onshore assets, and improving the integration of onshore wind in European grids using diversified energy vectors such as hydrogen or electric storage.

However, the maturity of the onshore wind sector needs to be recognised. In many markets such as the UK and USA, onshore wind is now generally accepted as tending towards cost parity with conventional forms of power generation, with a goal of 2020 having been set via the European Wind Initiative for total cost parity to be met across Europe. Wind onshore is still supported in most European countries, which indicates that the maturity of the onshore wind industry is not total, and that its market position is underpinned by support, as with other forms of power generation. However, energy is a highly dominated by different frameworks that alter the market value in many parts of the energy supply chain. The use of modelling tools, and the levelised consideration of the energy market, will lead to an increased maturity of the wind energy sector, reflecting the true added value of wind energy in the market price.

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The main focus of research and innovation in the offshore wind sector must be to drive down the LCOE through technology and market de-risking being translated into greater investor confidence, scaled-up production and reduced cost of project finance and insurance. Lowering the LCOE of offshore wind energy from c. €180/MWh to less than €120/MWh by 2025 is a significant challenge, but it must be addressed if offshore wind is to gain a significant market foothold and parity with other forms of generation.

In the onshore market, marginal reductions around system optimisation are likely to be the norm, amounting to c. 5-10% on existing figures. The technology has improved and cost improvements result from harmonising regulation. Wind energy has proved to be highly flexible to the demands from the different stakeholders (utilities, system operators, regulators, etc.), but this has led to variations within the EU. Harmonisation in the wind sector will lead to further cost reductions.

7.2 Adapting policies

Since the publication of the previous edition of the TPWind SRA in 2008, ambitious wind energy targets have been announced in EU and Member States to achieve the EU Energy 2020 goals[47]. However, there is currently no clarity as to what should follow the 2020 objectives, while the economic crisis and lack of clarity about Member States' support policies also create uncertainty.

By 2050[48], renewable energy and wind energy in particular will be the backbone of the EU energy system. For wind energy, onshore and offshore, the challenge will be to drive down costs and to compete with the other energies in a level playing field, where all the positive values are considered and the negative ones are mitigated, or charged in the final price of the kWh. Energy policies should integrate this levelised scenario and be clearly targeted and predictable, to ensure investor confidence.

[47] http://ec.europa.eu/energy/renewables/targets_en.htm

[48] Brussels, 15.12.2011 COM(2011) 885, Final Communication from the Commission to the European Parliament, the Council, the European and Economic and Social Committee and the Committee of the Regions – Energy Roadmap 2050.

The main priorities are:

- Stable support mechanism that maintains an objective of gradual elimination of subsidies as energy sources become mature;
- Strong and ambitious objectives up to 2050 based on Member States individual situations – resources, potential, development stage;
- Establishing binding targets for renewable energy;
- Maximising regional economic benefits by relying on local sources of energy, as long they are competitive in price/cost terms.

The economic impact of these proposals extends beyond the reduction of the cost per kWh: benefits include the regional development of industry, the development of a high added value industry, the reinforcement of the European industry presence and self-sufficiency in energy.

7.3 Optimising administrative procedures

The current administration of applications for wind farms and ancillary infrastructures in many parts of Europe are inconsistent. There are uncertainties in the requirements of consenting authorities and delays in the consenting process. This affects project development costs and risks, and could be an important source of cost reduction.

Despite policies supporting wind energy at the European and national level, in many Member States it is difficult to obtain planning consents for different types of projects.

In some Member States there is a lack of clarity over the administration requirements and processes for wind farm applications, particularly for repowering existing wind farms. Repowering projects pose additional challenges to those of developing new wind farms. The administration of applications for repowered wind farms needs to be clarified urgently, as repowering will become more common in countries where the first commercial wind farms are reaching the end of their lives and prime sites for wind farms are becoming scarce.

In order to optimise administrative procedures, the priorities would be:

- Encourage Member States to produce binding long term strategic plans for developing onshore and offshore wind farms. Within the identified areas, there should be greater certainty of consenting procedures and the administration should be streamlined. This framework should identify priority wind energy areas capable of meeting the future EU wind energy targets;
- Establish a one-stop-shop for Member States to provide guidance on consenting procedures. This entity should have clear procedures and deadlines that will lead to a greater clarity and a much more defined timeline for the different processes. This will also have an impact on the costs of developments, as the information about the designated areas will be known to all the players involved;
- Marine spatial planning should be carefully assessed following the latest benchmarking of the sector as defined in EU draft 2013/0074;
- Particular attention should be paid to offshore projects in which more than one country is involved. The development of these projects is a milestone for the EU and relevant administrative procedures should be coordinated for clarity and cost effectiveness. A complete maritime spatial planning approach must consider energy generation, wildlife conservation, and maritime transport routes, on an cross border basis within the EU.

Priority studies:

- As a matter of urgency, guidance should be produced on the administration of repowering applications;
- In order to have a reference for those countries with uncertain or inconsistent administrative procedures, establish a best practice reference to enable capacity building among relevant stakeholders. This framework will cover the installation, decommissioning and repowering of onshore and offshore sites;
- Review of wind farm, and auxiliary infrastructures' environmental impact assessments. This review should focus on how to streamline applications, e.g. by using the scoping stage to identify the key issues and to remove further assessment of impacts that are not relevant to the development. The review should suggest specific time limits for the individual steps in the consenting process.

7.4 Integrating wind into the natural environment

During the past decade there have been several investigations into the effects of wind energy on the natural environment. In countries like the UK, Denmark and Sweden, various national monitoring programmes have been initiated and some finalised. Environmental Impact Assessments (EIAs) and post-construction monitoring on existing wind farms have been carried out and conferences held, to bring the industry, authorities and researchers together. But the dissemination of knowledge regarding the effects of wind energy on the natural environment is still inadequate. The results are often not widely shared and in several Member States, resources are inefficiently used to repeat the same investigations.

Furthermore, wind energy in many Member States faces more strict regulation than other energy and non-energy installations, so the development of a benchmark of a more broad energy industry would be beneficial. Focus should be on research related to the environmental impact of renewable energy in a broader sense – electricity generation and consumption. In particular it should address global benefit of developing offshore wind farms compared to electricity from other sources.

Further research is needed into the potential impact of wind farms. Issues include:

- Potential effects on birds – focus on gaps in current knowledge and lessons learned;
- Potential effects on bats;
- Potential effects of underwater noise from piling of foundations (e.g., mono-piles or jackets) on marine mammals and fish;
- Cumulative effects, including population – or ecosystem-level impacts of wind farms;
- Social acceptance of wind energy, including a focus on noise.

To ensure that future monitoring adds to existing knowledge, attention should still be given to:

- Monitoring required when concerns remain after the implementation of an EIA;
- Monitoring that is goal and target-orientated, for which a clear scoping is essential;
- Termination of monitoring when sufficient data has been collected;
- Avoiding confusing monitoring with basic scientific research;
- Comprehensive evaluation of monitoring results in areas covered by the EIA, as well as the publication and sharing of these results within the energy industry.

The policy priority is to include offshore wind energy in national marine strategic plans. Moreover, the following issues need harmonisation across the EU:

- Potential effects of wind farms on radar;
- Aviation regulation.

Priority studies:

- Research into, and development of, guidance on the assessment of wind farms' environmental impacts, from local to global level and how to benchmark the industry vis-à-vis other energy and non-energy technologies;
- A centralised source of data describing the environmental baseline and impact should be established. Validation of data and development of methods to extrapolate results will be needed. This database would serve as guide for developers on the use and application of information to reduce or minimise the need for collecting new data;
- Research, guidance or common platform on the sharing and use of post-operational monitoring findings in future EIAs;
- Research into technological tools for monitoring and mitigating the impact of wind turbines on bats (with regard to under pressure), and marine mammals (with regard to under water noise). This includes studies to increase knowledge on behaviour and effects;
- Research into solutions and tools for addressing the impact and mitigation on radar, broadcasting telecommunications, etc.; their cost-effectiveness and funding of such solutions and tools, for example, transponders;
- Research into noise and social acceptance;
- Research into birds, including gaps in current

knowledge and lessons learned, further focus on species and situations;

- Research into and development of guidelines and tools to assess cumulative impacts, including population level impacts. This could involve the use and development of models;
- Harmonise and update aerial/aviation regulation as turbines get higher. This is a policy issue and should be dealt with from that perspective. Further research into technology development could be relevant.

7.5 Ensuring public acceptance of wind power

As a renewable energy source, there is a high level of acceptance and support for wind energy, compared to many conventional sources of energy generation[49]. Whilst there is large scale support for wind energy, wind farm applications can be delayed or blocked by resistance from local communities. The perception of a wind farm's impact on the environment and the cost of renewables, as well as the manner in which wind farms are developed, may play a greater part in shaping local acceptance than the actual physical impact. In order to increase acceptance for wind energy, it is essential to improve public awareness about wind energy and environmental impacts.

The industry can help to increase the level of acceptance by implementing best practice based on public consultation, remaining willing to address public acceptance issues and demonstrating improvements to reduce or mitigate issues of public concern. It is also important to involve local communities in the process of wind farm developments, and ensure that they reap some benefits. Increased focus on local benefits can improve local acceptance and facilitate future permit processes.

Research into the acceptance of offshore wind farms and the repowering of old wind farms, is increasingly important.

Priority studies:

- Investigate the motivation behind public opinion and people's concerns;
- Review case studies, looking at local opinion before and after the installation of wind farms;
- Review existing key concerns on wind energy and identify where further research is needed. Misinformation should be addressed, based on solid scientific studies;
- Review the range of mechanisms used across Europe for transforming global benefits into tangible benefits for local communities and identify how these can affect public opinion;

[49] Eurobarometer (Standard EB 74.3 on Energy): The Europeans and energy, http://ec.europa.eu/public_opinion/archives/ebs/ebs_pe_74-3_synth_en.pdf

- Review current best practice on effective consultation processes and local stakeholder management and the manner in which information is disseminated;
- Review case studies to identify and promote examples of positive effects of wind energy developments in different contexts, to clearly show benefits at local level;
- Increased focus on understanding the mechanisms behind social acceptance of wind energy in the offshore environment;
- Assessment of what factors are important for social acceptance in the context of repowering.

7.6 Human resources

The main HR drivers up to 2030 will be the increasing installed capacity, the onshore trend towards bigger turbines in lower wind speed regions, the offshore trend towards bigger turbines for deep water installation, repowering of old turbines in high wind speed regions and the need to cope with end of life requirements (especially for blades).

This will lead to a rising demand of jobs up to 2030, when the main driver will become O&M due to the increasing installed base. Job demand in other areas along the value chain is forecast to stay constant.

On the HR supply side a major constraint is related to demographics and a possible lag in training provision. A considerable gap exists especially in the so called STEM-topics (science, technology, engineering, and mathematics).

Furthermore education needs to incorporate industrial experience and benefit from its hands-on approach. To enable know how transfer in both directions, short term secondments for senior industry professionals or industrial scholarships are good solutions.

The wind industry also needs more generalists. As about 16% of the jobs in wind industry are in project development – their role is crucial[50]. Project developers are needed to develop, build and operate wind farms.

There should be an EU wide initiative to increase the number of master level graduates with a multidisciplinary skill set, which adds project management or wind farm development to technical capabilities.

Vocational education and training (VET) should be harmonized across Europe, since wind energy technology requires the same skills, wherever projects are located.

The O&M sector envisions a gap of 10,.000 employees until 2030. Training needs to be increased. One important element will be up-skilling, to cope with an increased qualification level required for O&M activities. Furthermore, O&M has to be carried out locally and therefore creates opportunities for local employment and growth. O&M capability for offshore needs to be increased in order to secure 2030 offshore capacity goals[51].

The competition between wind and oil and gas is a significant issue. Due to considerably different salary levels, O&M technicians tend to move from wind to oil and gas. This means that experienced workers are lost to the wind sector.

Also, the competition in the O&M sector increases productivity pressures on production and sourcing. The main focus needs to turn to a more globalised market of workers.

Priority studies:

- Quantify the need and level of O&M education in the EU and accession countries at national level and elaborate solutions for "skill and resource drain" towards high salary sectors like oil and gas, such as compensation schemes based on career development;
- Review current wind energy masters programmes and encourage the creation of new programmes, involving different European universities, e.g. the European Wind Energy Master[52];
- Quantify offshore related skills aligned with installation roadmap[53].

[50] Workers wanted: The EU wind energy sector skills gap European Wind Energy Technology Platform, August 2013, http://www.windplatform.eu/home/tpwind-report-workers-wanted-the-eu-wind-energy-sector-skills-gap/

[51] Offshore target referred to EWEA 150GW target by 2030, http://www.ewea.org/policy-issues/offshore/

[52] http://www.windenergymaster.eu

[53] Offshore target referred to EWEA 150GW target by 2030 http://www.ewea.org/policy-issues/offshore/

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8 FINANCING WIND ENERGY R&D

The European Wind initiative (EWI) requires a yearly investment of public and private resources in wind energy R&D of approximately €600 million (totaling €6 billion in 2010-2020)[54]. More than half of this amount should come from private investors, and the remaining part from public funds: 52% private (€3.1bn), 31% (€1.86bn) from the EU budget and the remaining 17% (about €1bn) from Member States' national programmes.

For many years wind energy R&D activities did not attract many public monies. Recently, though, the situation began to change and wind energy research received increasing support from the EU research framework programme, the European Energy Programme for Recovery (EEPR)[55], the NER300 mechanism and others. Public banks, such as EIB, EBRD, KfW also play an important role in financing innovative wind energy projects.

To reach the EWI's ambitious goals of making onshore wind energy the most competitive energy source by 2020 and for wind energy to reach penetration levels of 20% by 2020 and 33% by 2030, significant investments in R&D and project financing are crucial. EWEA estimates that achieving 30% wind energy penetration by 2030 will require annual investments of up to €25bn[56].

The industry is committed to bringing down the cost of wind energy and already has a positive track record in this respect. The wind industry spent more than 5% of its total turnover on research in 2010[57], which is two to three times higher than the economy-wide average. As a consequence, European companies are world leaders in wind power technology and have a leading share of the world market. EU support for demonstration and innovation will enable early deployment of innovative wind technologies and standardisation and will encourage economies of scale.

54 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0519:FIN:EN:PDF
55 http://ec.europa.eu/energy/eepr/index_en.htm
56 EWEA report Pure Power (2011).
57 EWEA report Green Growth (2012).

8.1 EU energy R&D funding

8.1.1 EU Framework programme for research

Although European financial support for research has increased significantly since the very first EU research framework programme FP1 in 1984, the FP-Energy R&D funding share within the overall EU R&D budget has declined from almost 30% in FP1 to below 5% in FP7 (for non-nuclear energy). Nevertheless, the new Horizon 2020 programme foresees almost €6bn (8% share) which is a substantial increase compared to the previous programmes.

As illustrated in the table below, wind energy R&D activities were underfunded for many years, however under the FP7-Energy programme wind sector signed almost 169 million euros worth grants. Additional 94 million was granted to wind research projects via other FP7 programmes[59].

8.1.2 European Energy Programme for Recovery (EEPR)

In 2009 the EU reached a political decision to set up a €4bn programme to co-finance energy projects aiming at increasing the reliability of energy supply in Europe and reducing the GHG emission and to boost Europe's economic recovery. The programme covered three broad fields: gas and electricity infrastructure, CCS and offshore wind.

Nine innovative offshore wind energy projects worth €565 million were selected to kick-start large-scale deployment of offshore wind located far from shore (more than 100km) and in deep waters (more than 40m), to establish the first offshore link serving as both the connection of the offshore wind farms and as a cross-border interconnector which is directly in line with EWI objectives.

A mid-term review of the EEPR has found that offshore wind energy was the strongest performer of the three areas selected for funding in terms of investment and job creation. Although just 14% of the programme's funds, the wind sector has successfully upscaled and connected to the grid innovative offshore wind farms, creating 4,000 jobs, which is 10 times compared to CCS[60].

8.1.3 New Entrants Reserve - NER300

The NER300 is the EU's funding programme for innovative demonstration projects for renewable energy and CCS. This programme combines what other EU programmes could only offer separately: support for the best innovative demonstration projects, direct involvement of the Member States, the European Commission and the EIB, high level leverage of private funds and national co-funding and stimulating jobs in innovative sectors.

Wind energy has 6 categories: onshore wind projects in cold climates and complex terrains; offshore wind floating systems and offshore wind farms with minimum turbine size of 6MW, 8MW and 10MW.

The first call, launched in 2011, awarded €1.2 billion to renewables projects – of which six wind energy projects granted €273 million. The awarded projects include innovative wind energy projects in cold climate, complex terrains, two floating systems and 2 offshore wind farms with 6 MW turbine size.

TABLE 10 EU ENERGY R&D FUNDING, FP1-HORIZON 2020[58]

EU Framework Programme for Research	EU FP for research overall budget, M €	FP-Energy (non-nuclear) budget, M €	Share of FP-Energy in the overall FP budget	Wind, M €	Share of wind in FP- Energy
FP1 (1984-1987)	2,810	830	29.5%	45.80	5.5%
FP2 (1987-991)	4,345	122	2.8%	7.59	6.2%
FP3 (1990-1994)	5,804	267	4.6%	58.82	22.0%
FP4 (1994-1998)	11,879	1,076	9.1%	44.10	4.1%
FP5 (1998-2002)	13,700	1,042	7.6%	70.00	6.7%
FP6 (2002-2006)	17,833	890	5.0%	39.00	4.4%
FP7 (2007-2013)	50,521	2,350	4.7%	168.6	7.2%
Horizon 2020 (2014-2020)	77,028	5,931	7.7%		

[58] Source: Council Decisions on the EU FP Research, Data from DG R&I, EC Cordis database (EWEA elaboration).
[59] FP7-People, FP7-SMS, FP7-Infrastructure, etc.
[60] http://ec.europa.eu/energy/evaluations/doc/2011_eepr_mid_term_evaluation.pdf

TABLE 11 EIB LOANS FOR WIND ENERGY PROJECTS 2005-2013

Country	Onshore, €	No of Projects	Offshore, €	No of Projects
Austria	508,200,000	9		
Belgium			1,083,000,000	8
Cyprus	44,450,230	1		
Denmark			240,000,000	1
Estonia	25,000,000	1		
Germany			2,338,474,367	10
Ireland	848,078,862	4		
Italy	200,000,000	1		
Poland	112,483,278	2		
Portugal	1,390,069,434	40		
Romania	205,809,630	2		
Spain	940,917,437	13		
United Kingdom	842,500,000	4	2,676,069,453	14
Total	**5,117,508,871**	**77**	**6,337,543,820**	**33**

Source: EIB project loans database, EWEA elaboration

8.2 EIB loans for wind

Public banks play an important role in financing innovative onshore and offshore wind energy projects where costs and risk factors are high and commercial banks are reluctant to intervene.

Between 2005 and 2013 the EIB granted more than €78bn[61] worth of loans to energy projects in the EU (mainly in Italy, Spain, UK, Germany and Portugal), most of which for electricity and gas infrastructure.

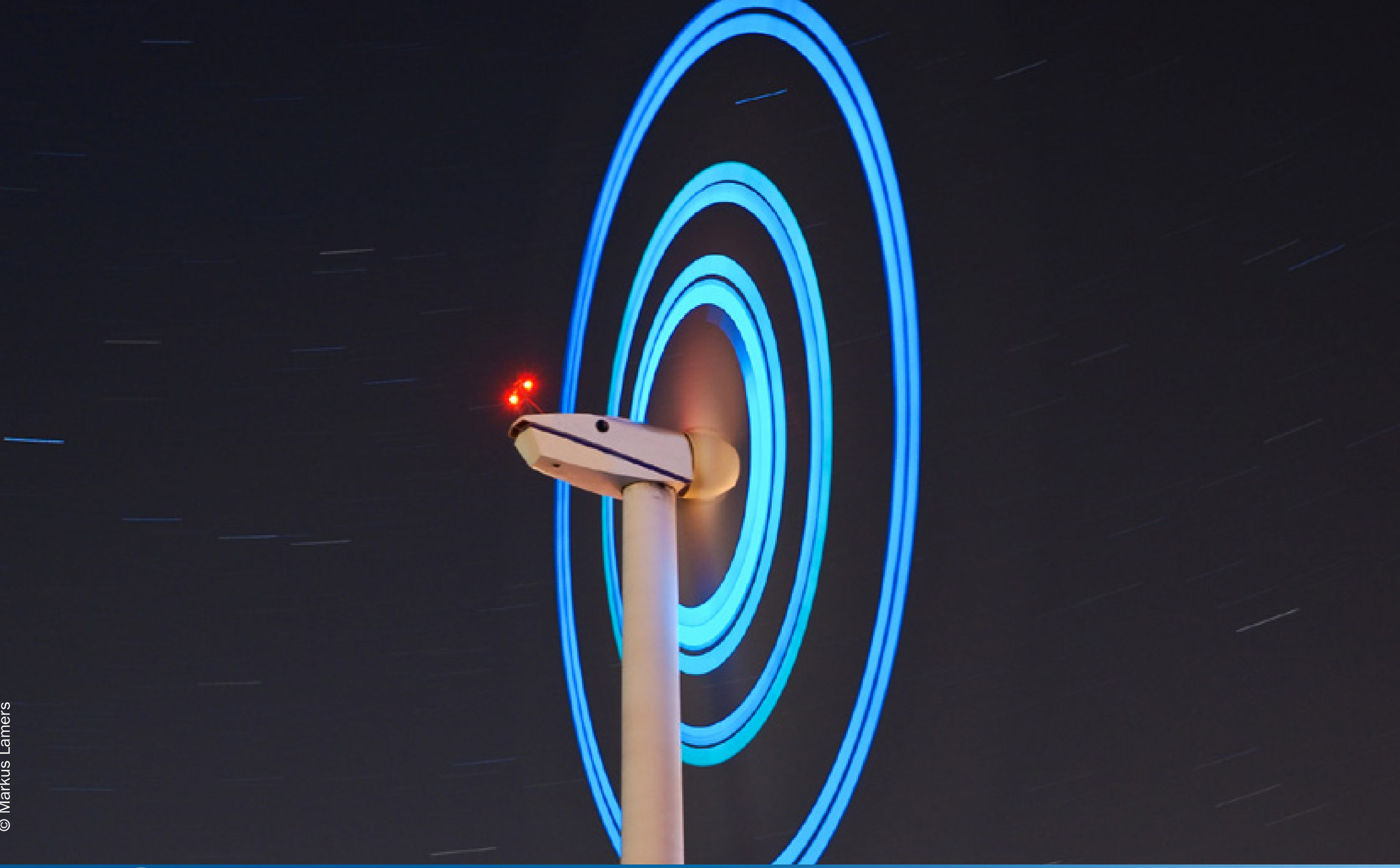
Renewable energy is also a significant part of the EIBs loans portfolio and wind energy projects received €11.5bn euros (14.7% of the total EIB energy loans) worth of loans which financed 77 onshore and 33 offshore projects.

The EIB will be playing a crucial role in financing innovative large scale wind energy projects offshore and the repowering process onshore.

8.3 TPWind recommendations

- The EU should maintain its political and financial support to the development of technologies in which it has technology leadership and which will have a major role in the future European energy system, such as onshore and offshore wind;
- To continue the successful development and innovations in wind energy technology the EU budget 2014-2020 (in particular the research programme Horizon 2020 and the Cohesion funds) must prioritise the wind sector as a job creating industry which will significantly contribute to achieving the EU's energy policy goals;
- The SET-Plan, and in particular the European Wind initiative, must be fully implemented and prolonged post-2020. The EWI should be financed through a dedicated EU budget line, additional instruments and other financing tools and lending schemes should be introduced to support this programme and to leverage private investments;
- In the post-2020 period, the EU budget must increase further the funding for renewable energy technologies and establish new financial instruments and programmes such as a new NER300;
- Future EU research and innovation policy stemming from the Communication on energy technologies and innovation[62] should address the technology needs and support EU industrial leadership by increasing focus on renewable energy R&I, in particular wind energy technology;
- The industry and decision makers should enhance the cooperation with public banks, such as the European Investment Bank.

[61] EWEA calculations based on the EIB project database http://www.eib.org/projects/loans/sectors/energy.htm
[62] http://ec.europa.eu/energy/technology/strategy/doc/comm_2013_0253_en.pdf



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9 TPWIND STRUCTURE AND MEMBERS

TPWind is currently structured in five working groups, looking at the different aspects of the wind energy sector, and a steering committee. An advisory board, composed of external stakeholders guarantees discussions and know-how dissemination on cross-cutting issues with other sectors.

9.1 Working Groups

- **Working Group 1: wind conditions**
  This Working Group has to focus on areas where wind exploitation is still poor, for enabling the full deployment of wind energy. Particular emphasis is given to offshore and extreme climate resources.

  Key areas in this thematic may include: advanced siting and wind characterization models. Wind resource mapping, advanced wind power forecasting techniques, advanced measurement techniques including remote sensing, etc.

- **Working Group 2: wind power systems**
  This working group focuses on aspects enabling costs reductions on the wind-turbine side (onshore and offshore).

  Key areas in this thematic may include: Materials, Drive-trains, Blades, O&M and Wind turbine design and efficiency.

- **Working Group 3: grid integration**
  The scope of this working group work extends from the single (large) wind farm level (onshore and offshore) to the large-scale integration in the power system level. The layout and basic structure of the grid need to be adapted to large amounts of variable electricity supply.

  Key areas in this thematic may include: Grid codes/ communication standards, Grid structure and planning, Grid operation and energy management (prediction tools, probabilistic capacity planning, storage facilities), Energy market integration (converting stochastic wind energy production into energy market products, providing additional grid services to TSO's and DSO's).

- **Working Group 4: offshore**
  This working group focuses on offshore research and deployment. Key areas in this thematic may include: safety and access to offshore turbines, new and improved concepts for offshore wind turbines, design and fabrication of offshore substructures, new concepts for assembly installation and hookup of large scale developments, offshore cables and connectors, operations and maintenance, spatial planning and decommissioning.

- **Working Group 5: environment and deployment**
  This working group focusing on environmental impact, social acceptance, spatial planning and the economic impact of R&D and innovation. Key areas in this thematic may include: cost and financing of wind turbine and wind farm projects, EIA guidelines on environmental impact, end-of-life policies, radar issues, on and offshore spatial planning.

9.2 Steering Committee

The Steering Committee is the decision-making body and executive arm of TPWind. Five Steering Committee members, elected for an 18-months period, form the Executive Committee, which is the primary link between the Steering Committee and the Secretariat.

9.3 Advisory Board

The Advisory Board was created in 2011 and is composed of external stakeholders (i.e. non-Platform members) who help TPWind to enhance its network and effectiveness by providing advice and contacts. They represent an essential link between the Platform and other relevant sectors and stakeholders.

They also act as a quick access point to the expertise and know-how developed by other sectors, which is essential to reduce fragmentation of R&D activities.

The Advisory Board is not a decision-making body of the Platform, but has a consultative role.

9.4 Secretariat

The Secretariat provides logistical, organisational and content-based support for TPWind's activities.

The Secretariat is made up of EWEA, GL Garrad Hassan and Risoe/DTU and is under contract to the European Commission.

9.5 TPWind Members

9.5.1 Executive Committee

Chairperson
- Henning Kruse – *SIEMENS Wind Power*

Vice-chairpersons
- Allan MacAskill – *MacAskill Associates*
- Mauro Villanueva – *Gamesa*

Alternates
- Hannele Holtinnen – *VTT*
- Peter Tavner – *University of Durham (retired)*

9.5.2 Steering Committee

- Mike Anderson, *RES*
- Jos Beurskens, *ECN (retired)*
- Takis Chaviaropoulos, *CRES*
- Dolf Elsevier van Griethuysen, *Ballast Nedam*
- Lars Gertmar, *ABB (retired)*
- Christoph Hessel, *GE Wind*
- Koen Hoedemaekers, *ZF Wind Power*
- George Kariniotakis, *MINES Paris Tech*
- Izabela Kielichowska, *GE*
- Lars Landberg, *GL Garrad Hassan*
- Wiebke Langreder, *Wind Solutions*
- Jens Ingemann Madsen, *Vattenfall*
- Ignacio Marti, *NAREC*
- Christian Nath, *Germanischer Lloyd (retired)*
- Erik Lundtang Petersen, *DTU Wind*
- Pep Prats, *Alstom*
- Angeles Santamaria, *Iberdrola*
- John Tande, *SINTEF*

9.5.3 Secretariat

- Iván Pineda, *EWEA*
- Manuela Conconi, *EWEA*
- Jacopo Moccia, *EWEA*
- Vilma Radvilaite, *EWEA*
- Peter Hjuler Jensen, *DTU Wind*
- Alfredo Peña Diaz, *DTU Wind*
- Gregor Giebel, *DTU Wind*
- Anand Natarajan, *DTU Wind*
- Carlos Albero, *GL Garrad Hassan*

9.5.4 Working Group 1: external conditions

- **Chairperson: Wiebke Langreder, *Wind solutions***
- Kamil Beker, *EPA Sp. Zo.o.*
- Tomas Blodau-Konick, *SENVION SE*
- Oisin Brady, *Natural Power*
- Lars Christian Christensen, *Vestas*
- Miguel Ferreira, *Megajoule*
- Maria Galainena, *ENEL Green Power*
- Patrick Hoebeke, *3E*
- Jørgen Hojstrup, *ROMO Wind A/S*
- Vincent Kerbaol, *CLS*
- Lars Landberg, *GL Garrad Hassan*
- Bernhard Lange, *IWES*
- Gil Lizcano, *Vortex*
- Alegre Herrero Mar, *Gamesa*
- Miriam Marchante, *DONG*
- Ignacio Martí, *NAREC*
- José Carlos Matos, *INEGI*
- Ivan Moya Mallafre, *CENER*
- Thorben Gonzalez Nielsen, *SIEMENS Wind Power*
- José Palma, *Porto University*
- Joachim Peinke, *ForWind - Centre for Wind Energy Research*
- Evangelos Politis, *Vestas*
- Luis Prieto Godino, *Iberdrola*
- Herbert Schwartz, *Anemos-Jacob*
- Anders Sommer, *Vattenfall*
- Peter Stuart, *RES Ltd*
- Jeronimus Van Beeck, *Von Karman Institute*
- José Vidal, *AWS Truepower*
- Rafael Zubiaur, *Barlovento*

9.5.5 Working Group 2: wind power systems

- **Chairperson: Jos Beurskens, *ECN (retired)***
- Christina Aabo, *DONG Energy*
- Georg Adolphs, *Owens Corning*
- Ulrich Bast, *SIEMENS*
- Raquel Chamocin, *Iberdrola*
- Peter Hermann Dalhoff, *Hamburg University*
- Alex De Broe, *3E*
- José Antonio de la Torre Quiralte, *Gamesa*
- Jan Declercq, *CG Holdings*
- Remi Dornier, *Dassault*
- Peter Eecen, *ECN*
- Christer Eriksson, *Det Norske Veritas*
- Jochen Giebhardt, *IWES*
- Olivier Grammont, *Fairwind*
- Ben Hendriks, *GL Garrad Hassan*
- Koen Hoedemaekers, *ZF Wind Power*
- Sebastian Johansen, *Fortum*
- Martin Knops, *SENVION SE*
- Martin Kühn, *ForWind - Centre for Wind Energy Research*
- Denja Lekou, *CRES*
- Paul McKeever, *NAREC*
- Xabier Munduate-Etxarri, *CENER*
- Jaco Nies, *GE Wind Energy*
- Jordi Puigcorbé, *Alstom*
- Flemming Rasmussen, *DTU Wind*
- Felipe Sanchez Cid, *ENEL Green Power*
- Frieder Schuon, *IREC*
- John Dalsgaard Sørensen, *Aalborg University*
- Don R.V. van Deflt, *Knowledge Centre WMC*
- Jan-Willem van Wingerden, *Delft University*
- Jens Jakob Wedel-Heinen, *Vestas*
- Anders Wiisbye, *SIEMENS Wind Power*
- Alberto Zasso, *Politecnico di Milano*

9.5.6 Working Group 3: grid integration

- **Chairperson: George Kariniotakis, *MINES Paris Tech***
- Monica Aguado Alonso, *CENER*
- Vladislav Akhmatov, *Energinet*
- Urban Axelsson, *Vattenfall*
- Ulrich Fochen, *Energy & Meteo Systems*
- Michael Nørtoft Frydensbjerg, *SIEMENS Wind Power*
- Paul Gardner, *GL Garrad Hassan*
- Emilio Gomez Lazaro, *Castilla-La Mancha University*
- Klaus Baggesen Hilger, *DONG Energy*
- Jakob Lau Holst, *Danish Wind Industry Association*
- David Infield, *Strathclyde University*
- Philip Carne Kjaer, *Vestas*

- Korpas Magnus, *SINTEF*
- Hervé Mariage, *Schneider Electric*
- José Miguel Miranda, *Gamesa*
- Alberto Molina, *Energy 2 Quality*
- Albert Moser, *Aachen University*
- Szymon Nowak, *EPA Sp. z o.o*
- Dusan Opacic, *Sirius Regulus d.o.o. / Netinvets*
- Juan Carlos Perez, *Iberdrola*
- Kurt Rohrig, *IWES*
- Marc Sala, *Alstom*
- Volker Schulz, *SENVION SE*
- Paula Souto, *WindVision*
- Poul Sørensen, *DTU Wind*
- Jens Tambke, *ForWind - Centre for Wind Energy Research*
- Adrian Timbus, *ABB*
- Frans Van Hulle, *XP Wind*
- Stephan Wachtel, *GE Energy*
- Achim Woyte, *3E*

9.5.7 Working Group 4: offshore

- **Chairperson: John Olav Tande, *SINTEF***
- Kimon Argyriadis, *Germanischer Lloyd Industrial Services*
- Felix Avia, *CENER*
- Georg Barton, *RWE*
- Thomas Buhl, *DTU Wind*
- Daniel Castell Martinez, *Alstom*
- Gareth Craft, *The Crown Estate*
- Göran Dalén, *WPD*
- Christine De Jouëtte, *Areva*
- Vincent De Laleu, *EDF Energy*
- Theo De Lange, *Van Oord Offshore Wind Projects*
- Phil De Villiers, *The Carbon Trust*
- Luc Dewilde, *3E*
- Michael Durstewitz, *Fraunhofer Institute*
- Dolf Elsevier van Griethuysen, *Ballast Nedam*
- Pietro Gimondo, *Centro Sviluppo Materiali* SpA
- Jørn Scharling Holm, *DONG Energy*
- Jerome Jacquemin, *GL Garrad Hassan*
- Tim Klatt, *Bilfinger Berger Ingenieurbau GmbH*
- Jaco Korbijn, *Blue H*
- Peter Hauge Madsen, *DTU Wind*
- Raul MAnzanas, *Acciona*
- Luis Martin, *Iberdrola*
- Finn Gunnar Nielsen, *StatOil*
- Thomas Østergaard, *DONG Energy*
- Franco Sansone, *ENEL Green Power*
- Peter Schaumann, *Forwind-Center for Wind Energy Research*
- Kurt Thomsen, *Advanced Offshore Solutions*
- Carlo Tricoli, *ENEA*
- Jan Van der Tempel, *Delft University*

9.5.8 Working Group 5: environment and deployment

- **Chairperson: Izabela Kielichowska, *GE***
- Stephan Barth, *ForWind - Centre for Wind Energy Research*
- Marta Benito García-Morales, *EDF*
- Charlotte Boesen, *DONG Energy*
- Alberto Ceña, *Asociación Empresarial Eólica*
- Aidan Cronin, *SIEMENS Wind Power*
- Imar Owen Doornbos, *Dutch Ministry of Economic Affairs*
- Jacob-Jan Ferweda, *WindVision*
- Andrea Gattini, *ENEL Green Power*
- Magali Gontier, *Laborelec*
- Christoph Gringmuth, *GE Wind Energy*
- Ge Huismans, *Agentschap NL*
- Alan Lowdon, *Sinclair Knight Merz*
- Claudio Mascialino, *Adventum*
- Sara McGowan, *Vattenfall*
- Steffen Nielsen, *Danish Ministry of Foreign Affairs*
- Marta Rafecas, *Gamesa*
- Sune Strom, *Danish Wind Industry Association*
- Colin Thomas Warwick, *The Crown Estate*
- Pavel Wloch, *EPA Sp. z o.o.*

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TPWind

TPWind aims at enhancing communication within the wind energy sector, improving its visibility and impact, spreading information on relevant R&D achievements and developing strategic pathways for the growth of the sector (such as the implementation of the European Wind Initiative, a long-term, large-scale programme for supporting wind energy R&D, developed by TPWind in cooperation with EU Institutions and Member States and launched in 2010).

The platform gathers stakeholders from the wind energy industry and R&D community as well as representatives of other sectors/ stakeholders for ensuring the development of relevant synergies.