Strategic research and innovation agenda 2016

September 2016

European Commission

ETIP Wind

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EUROPEAN TECHNOLOGY & INNOVATION
PLATFORM ON **WIND ENERGY**

Strategic research and innovation agenda 2016

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Tender project number: PP-03041-2014
EC contract 2015/RTD/OP-03041-2014

The ETIPWind secretariat would like to thank all those who contributed to drafting and producing this report. In particular, we wish to gratefully acknowledge the members of the ETIPWind Steering Committee and Advisory Group.

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Foreword

No report can stand in isolation of its time, place and environment. The two paragraphs below give some of the perspectives that form the background for this Strategic Research and Innovation Agenda (SRIA).

Wind power in today's energy arena

The cost of wind energy has continued to fall despite the polluter pays principle still not being fully applied in most markets. This is an achievement to be proud of and has been driven by intense research and innovation. However, academia and industry need to work together more closely to drive costs down further making wind energy a technology of first choice.

The pressure on renewable energy is increasing as energy commodity prices (coal, oil, and gas) are at historically low levels in real terms. Electricity demand in the developed world will continue to decrease in the short term due to increas¬ingly lean production technologies, energy efficiency, and the emergence of postindustrial societies.

Public and political support for renewables has weakened in some regions. R&I has to address this challenge, as losing the battle of maintaining European leadership will damage the industry's future. As compe¬tition between technology providers is becoming fiercer in developed markets, high growth markets move to the developing world and European leadership is increasingly challenged, especially by Asian players. They are investing vast sums in wind power and storage related research and Europe needs to meet this challenge.

Main opportunities and challenges ahead

The way we use energy will change dramatically. This will trigger many opportunities and challenges to overcome in the short and long-term future.

Electrification of transport *– The coming high penetration of electrical vehicles will drive up the electricity demand dramatically in the long-term. Airborne pollution in a world with increasing urban concentration makes shifts to electrified transport vital for the healthy survival of these populations. Wind power has to be "charge ready" and due to its geographical spread, it should have a vast impact in supporting the expansion of electrical vehicle use.*

Climate change *– Our power system and infrastructure will be increasingly vulnerable to extreme weather events as climate change drives extreme temperatures, storms, flooding and droughts. Wind energy will have to be a stable and central element of the grid with enhanced grid support and standalone capabilities.*

***Pressure on water reserves** – Increasing pressure on fresh water will call for more purification and desalination - again wind due to its fuel price independence is well placed to process and store clean water for controlled use as needed. Power generation without water-cooling will be necessary.*

***Analytics and Big Data** – They are shaking the energy sector. Software being developed for grid operators, asset managers and customer services can help integrate wind and other renewable energy systems more effectively, enhance a better interaction between all stakeholders and unleash new opportunities for cost reduction.*

***Smart society** – The smartphone-enabled society will drive easy access for end users at both industrial and consumer levels to detailed power consumption planning. Whether the power system will follow trends in the mobile industry and become more wireless or local as developments in storage technologies may offer power anywhere solutions remains to be seen. Wind power, with its high level of geographical dispersion will be well placed to work in such a power system. The future power system will increase its flexibility, notably thanks to interactive software interfaced with smart grids, demand-side management, power-to-gas/-heat/-cooling, and battery storage (including electric vehicles). Photovoltaics will continue to grow at an exponential rate and wind power system designers need to optimise the interfaces between these two technologies for maximum synergies to be realised.*

Anticipating, preparing, and mitigating the above challenges is vital to Europe and global society at large. This SRIA is a snapshot of how research should be put in place to deliver what the European wind energy sector needs to maintain its lead in European and global terms going forward. The snapshot will change and the SRIA gives a lens to observe these changes and the opportunity to adjust the strategic focus of R&I accordingly.

The ETIPWind forum supports a unique environment for academia and industry to forge some common research goals to deliver a beacon for European and national research programmes, which ensure relevance, continue to drive down the cost of wind energy and maintain its place as an abundant, clean, natural, sustainable and fuel free power generation technology.

On behalf of the ETIPWind Steering Committee[1], I would like to thank the European Commission for its support of the ETIPWind forum and making this publication possible.

Personally, I would like to also thank all the participants in the ETIPWind Advisory Group[2], the Steering Committee and not least the hard working members of the secretariat[3] and also all those outside these main groups for using their time to contribute to a refined focus.

Aidan Cronin
ETIPWind Chairman

1. See page 64
2. See page 66
3. See page 67

"European Technology and Innovation Platforms play an important role in building the Energy Union bottom-up, making our energy system fit for the future. I therefore welcome the ETIPWind's Strategic Research and Innovation Agenda which enriches the public debate on how EU policies can transition our society to low-carbon"

Maroš Šefčovič, Vice-President of the European Commission, in charge of the Energy Union

"As Europe rapidly advances towards a power system with a large amount of wind and other renewable power sources, it is clear that accommodating even more renewables will be limited by technical barriers related to the interconnection infrastructure and overall system operation. Research on this emerging renewably-fueled power system is imperative to arrive at solutions that could break such barriers and enable the integration of even more and optimal use of all renewable energy sources. Funding of directed research will help solve practical problems (e.g. decreasing inertia in the system) and will ensure Europe maintains its leadership on renewable energy."

Ernst Scholtz – Group R&D Strategy Manager, ABB

"With an installed capacity of more than 142 GW, the European wind power fleet has never been so massive. Wind farm customers and manufacturers face many challenges on the way to better availability and reliability. Gathering and analysing continuous flows of data from the thousands of wind farms will ultimately lead to significant cost reductions at the operation and maintenance level and give wind the place it deserves in the European power system."

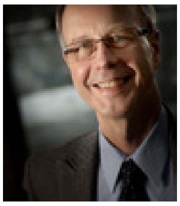
Cristina Heredero Bueno – Head of the Technology and Sustainability Department in the Renewable Business, Iberdrola

"The wind power industry has developed at a very fast pace thanks to constant innovations driving its cost of energy down. Industrialisation will take the sector to the next level, thereby optimising the whole value chain, providing faster products and services to the market and exploiting economies of scale and maintaining a strong supplier industry with state of the art technologies."

Anders Vedel – CTO Turbines R&D, Vestas

"Offshore wind energy is still a young industry – it took off 10-15 years ago and since then it has developed, grown and matured at a breath-taking pace. Yet, there is still a lot of room for improvement and development, not least when it comes to industrialising the balance of plant, i.e. foundations and electrical systems. DONG Energy has pioneered offshore wind energy and is fully committed to continue to develop better and more cost-efficient solutions for the future - in collaboration with the wider industry and academia. The target is that offshore wind energy is competitive with other technologies, and recent auctions have shown that the work for cost reduction is on track. However, there is still a big need for cost reduction, innovation and development, as future offshore wind farms will be built with larger turbines and foundations, further from shore and at deeper waters. So there are still a lot of challenges to overcome and costs to be cut, and therefore research, innovation, development and demonstration is still needed on a big scale."

Christina Aabo – Head of R&D, Dong Energy Wind



"In the medium to long term, wind power requires a strong scientific knowledge base to develop beyond its activities of today and tomorrow and maintain its competitive edge through technological leadership. Out-of-the-box technological advances can trigger breakthrough technologies that could create new opportunities for the wind energy sector."

Peter Hauge Madsen – Head of Department, DTU Wind Energy

Executive summary

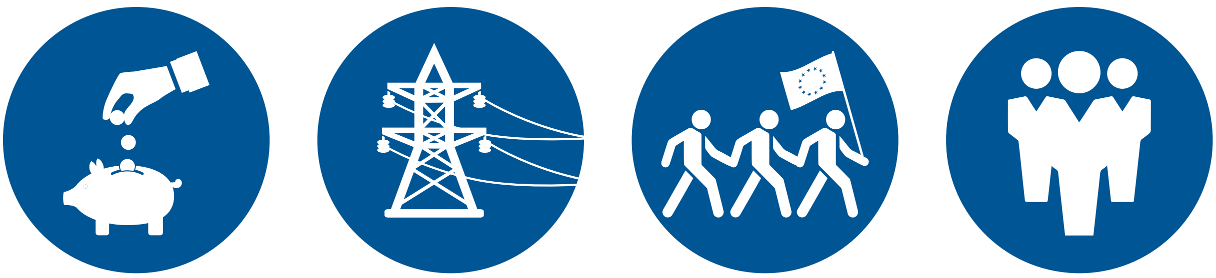
In 2015, wind energy represented more than 11% of power generation in Europe[4], also providing 331,000 jobs in the continent[5]. Wind power already plays a key role serving our societies' needs for sustainable, local, secure and low-cost electricity, powering an equivalent of 87 million European households[6]. The electricity decarbonisation needed by the European Union and its member states will drive a switch in generation technology. Simultaneously, the pending electrification of transport and heating will trigger new demand for electricity, allowing wind capacity to grow sharply from 142 GW today[7] up to 225 GW by 2025[8].

Over the last 10 years, the wind industry has matured at a fast pace, achieving significant cost reduction by constantly innovating. Further **cost reduction** can be achieved through a better allocation of EU research and innovation funds.

The development of the European grid is fundamental to ensuring a secure electricity supply with higher shares of renewable sources. Furthermore, wind energy needs to do more to **facilitate its system integration**, and its contribution will grow as research progresses over the years.

As international competition increases, **maintaining European technological leadership** is key to preserving our competitive advantage in the sector. In this respect, **ensuring first-class skills and human resources** is also key to further upcoming wind developments.

FIGURE 1
Objectives of the Strategic Research and Innovation Agenda 2016



Reduce costs

Facilitate system integration

Reinforce European technological leadership

Ensure first-class human resources

4. Electricity production and supply statistics for 2015, ec.europa.eu, 2016
5. Renewable Energy and Jobs Annual Review 2016, IRENA
6. With an EU average annual household consumption of 3.6 MWh and annual wind generation of 315 TWh in 2015 according to WindEurope statistics
7. EWEA yearly statistics 2015
8. World Energy Outlook 2015, IEA, 2016, new policies scenario

5 pillars of research and innovation for wind energy

Research and innovation will play a fundamental role in achieving these objectives, and we need a strategic vision to shape future R&I priorities. A shared vision for Europe's R&I is now reflected in this Strategic Research and Innovation Agenda. This vision recommends that action focuses on addressing the following key challenges:

GRIDS SYSTEMS, INTEGRATION AND INFRASTRUCTURE

Developing wind energy capabilities to fit in a grid with significant shares of renewable energy.

OPERATION AND MAINTENANCE

More and further enhanced sensors enabling more reliable and efficient operation and maintenance of turbines, improving yields and optimising lifetime.

INDUSTRIALISATION

Developing the value chain and facilitating the interaction between stakeholders notably through standardisation to achieve economies of scale and faster production.

OFFSHORE BALANCE OF PLANT

Exploring new areas for offshore wind and making it competitive with conventional generation through the improvement of substructures and foundations, site access, offshore grid infrastructure, assembly and installation.

NEXT GENERATION TECHNOLOGIES

Consolidating the scientific base for wind research and enabling pioneering research to lead to breakthroughs.

FROM R&I TO DEPLOYMENT

Adapting markets and policies for optimal integration of renewables, integrating wind turbines into their natural surroundings, ensuring public engagement and acceptance and deploying human resources.

1. Grid systems, infrastructure and integration

As wind energy becomes a mainstream source of power generation, turbine technology and the power grid must develop accordingly. R&I has to contribute to a better understanding of the interaction between wind turbines and the power system and the development of stronger grids which can handle higher amounts of renewable energy.

Targets

- Develop wind farm capabilities to facilitate larger shares of renewables in the grid;
- Develop wind power to provide enhanced grid services;
- Improve the reliability of cables and other key grid components around the turbines; and
- Improve integration of wind energy through an enhanced interaction with energy storage, demand response and smart interconnection with other technologies.

Key action areas

1.1 Energy management and balancing with other renewable sources

With higher shares of wind power in the system, the need for better energy/demand management and balancing services is likely to increase. The development of more accurate and longer term forecasts for wind generation could facilitate the integration of wind power and provide a stronger predictability of wind assets. Also, the development of enhanced virtual power plant and substation concepts could help to improve wind farm management.

1.2 Control and design of turbines and wind farms for the provision of ancillary services

At large penetration rates wind power generators need to provide grid services where and when needed. R&I should focus on developing wind power capabilities to provide ancillary services at both individual turbine and wind farm level. Services such as frequency and voltage support as well as the ability for wind farms to act as standalone generation could enable increased support to the grid. To do so, enhanced test and verification should contribute to the delivery of standardised solutions.

1.3 Improved transmission systems including their operation and maintenance

Grid constraints must not affect wind market development. To enhance power grids, R&I will should focus on increasing the reliability of cables and other key transmission components, including their operation and maintenance. In addition, improvements in electrical collection systems could increase the amount of wind power to the grid. Finally, the development of innovative grids could also help offshore wind in reducing costs.

1.4 Energy storage

Enhanced energy storage could offset the variability of wind energy. The development of balancing, ancillary services, bulk storage and charging electrical vehicles, would allow for a better integration of wind power.

2. Operation and maintenance

Improved operation and maintenance is crucial to drive down costs. With a large number of turbines now in operation, the wind industry has never had so many sources of information and data available. Wind energy operators should continue to make better analyses and use them to improve the design of machines, components and servicing systems.

Targets

- Capture more relevant data and improve the accuracy and reliability of data streams and improve analytical models;
- Achieve cost reduction in O&M due to improved data analyses;
- Improve energy yield through enhanced O&M procedures; and
- Increase or extend the lifetime of turbines and develop streamlined end-of-life strategies.

Key action areas

2.1 Standardised validated sensor systems for performance measurement and condition monitoring

The first step to gathering high amounts of relevant data is to improve the design and quality of sensors that are installed in or close to the turbines. Increased accuracy and robustness of sensors will form the basis of high quality, selective and low cost data gathering. New technologies such as airborne drones or autonomous mobile robotic units will open up new possibilities for data collection.

2.2 Realtime testing, adaptive, interactive technologies and big data control to improve energy yield

Improved data collection could optimise the operation and maintenance of turbines. The development of interactive big data analysis tools could optimise energy yield, while protecting the structural, mechanical and electrical condition of the machines.

2.3 Tools for data analysis, diagnosis and O&M strategies to improve reliability and predictability of failures

Big data analysis could help identify root causes of sequential events leading to failures, which causes downtime. Effective data analysis will enhance maintenance strategies, including predictive maintenance, and this will support cost reduction.

2.4 Lifetime optimisation

Improved data cluster analysis could optimise wind turbine lifetime. A better understanding of fatigue loads and the erosion of blades could allow for enhanced turbine operation, possible lifetime extension and/or repowering.

3. Industrialisation

Industrialisation is one of the key enablers to reduce the cost of wind power. It represents a natural step that the wind sector has to take in order to achieve economies of scale and better cooperation along the entire value chain. While some wind turbine components are already standardised, many still need the level of standardisation seen in other industrial sectors. Also, most wind energy projects are run as one-off, turnkey, customised projects rather than as a series of projects with similar requirements.

Targets

- Enhance better collaboration between all the different stakeholders of the value chain;
- Create common market requirements to trigger cost and time savings; and
- Develop cross-licensing as in other industries.

Key action areas

3.1 Standardisation

The idea of standardisation is to take advantage of the similarities between different projects in order to introduce large cost and time savings for all involved stakeholders. Efficient standardised products and concepts play an important role at all the stages of component design, manufacturing, installation, construction servicing and decommissioning. The whole industry could benefit from standardisation of logistics, products, methods and digitisation.

3.2 Regulatory market requirements and harmonisation

Today, many design requirements are set at national level. This causes important project development costs, particularly offshore, that harmonisation could prevent. All aspects, from aviation requirements to quality certification can benefit from further R&I work on harmonisation at European level.

3.3 Value chain development

The wind energy industry and academia should work on smarter standard solutions to strengthen the value chain towards industrialisation in order to deliver lower cost solutions at a higher pace.

4. Offshore balance of plant

The critical priority for offshore wind is to significantly lower its cost in order to become competitive with conventional generation by 2025. There is still a significant potential for cost reduction for offshore wind. The biggest and hence most crucial fixed cost is the balance of plant, which includes substructures and foundations, site access, offshore grid infrastructure, assembly and installation. It is vital for Europe to improve this area to maintain its current lead in offshore technology.

Targets

- Achieve LCOE of €80/MWh (including grid connection) at FID[9] for all offshore wind power projects by 2025;
- Improve and standardise installation and assembly methods;
- Create optimised foundations at a lower cost;
- Define and develop the right electrical infrastructure with increased reliability for offshore wind power; and
- Bring floating offshore wind towards an industrialised competitive level.

Key action areas

4.1 Industrialised transport and installation systems

Transport and installation systems need to reach an industrialised level to achieve the ambitious cost reduction of the offshore wind sector. These sectors will face new challenges: the increase in the size of the turbines and installation at greater water depths will trigger the need for new vessels and system design.

4.2 Innovative and industrialised offshore towers and foundations, including better seabed interaction

The development of innovative substructure designs for offshore wind power needs to target higher reliability at the lowest cost. A better understanding of the interaction between the seabed and the foundation is key to optimise designs and reduce costs.

4.3 Floating offshore wind farms

Floating wind power is still in its infancy. R&I needs to bring it to the next level in order to unleash the massive potential of deep seas. The main challenges lie in the design of robust and reliable floating foundations, their installation, and optimised operation and maintenance.

4.4 Innovative and industrialised offshore substations and cables

R&I should focus on offshore electrical infrastructure as it represents a significant cost for offshore wind. Particularly, regulatory requirements and standardisation require in-depth analysis to lower the overall cost of projects. New technology developments, notably on cables, offshore substations and HVDC technologies can also contribute to further cost reduction. Common connection rules between different grid jurisdictions are also key to explore.

5. Next generation technologies

In order to develop beyond the activities of today and tomorrow, the wind energy sector also needs a strong scientific base which involves fundamental and pioneering research. This groundwork shall address the long-term applications and stimulate breakthrough possibilities.

Targets

- Open the possibility for breakthrough research and game changers;
- Develop intelligent materials for wind turbines;
- Consolidate the scientific base for wind energy to cement progress and educate the next generation of wind pioneers;
- Minimise the uncertainty associated with wind energy; and
- Improve testing and measurement of wind turbines.

9. Final investment decision

Key action areas

5.1 Disruptive technologies

Researchers need to look for game changers for wind energy. Out-of-the-box technological advances especially in the rotor and generator are an opportunity for breakthroughs that should not be neglected.

5.2 Next generation tests and measurements

Novel measurement techniques and experimental tests, including new aerodynamics and aeroelasticity test benches, are necessary if we are to improve the quality of turbines.

5.3 Smart Rotor design

The research for new smart rotor designs will help reducing the cost of wind power by improving energy yields, while managing better fatigue loads and limiting noise emissions. This includes enhanced aerodynamic and aeroacoustic modelling.

5.4 Matching site conditions

Minimising the uncertainty and improving the predictability of wind energy, including in complex terrains, is an important driver for reducing the cost of wind energy.

5.5 Materials and structures

The use of materials in the turbine needs more investigation in order to improve the structural integrity of the machines. Consolidating the knowledge on current materials and investigating the need to use new materials is key to achieve lighter, stronger, more sustainable and more economical structures.

5.6 Wind farm control

Advanced control at wind farm level can be developed to actively monitor the flow field, anticipate wind changes, and modify the flow through the wind farm by redirection of the turbine wakes. Such wind farm control can have the double benefit of increasing total wind farm performance and at the same time reducing the risk of unwanted dynamic loads and turbine interactions that can result in increased fatigue loads. Work in this area focuses on analyzing and optimizing the wind plant from a system level rather than an individual turbine level.

6. From R&I to deployment

R&I needs to explore new solutions that will enable wind energy to be one of the main contributors to the climate and energy targets set by the European Commission. This must be done in parallel to the technological research described above in order to remove the barriers to massive deployment.

6.1 Adapting markets and policies

Policies and electricity markets can make wind power thrive. However, the current market design does not enable optimal integration of large shares of renewables. Some of the economic incentives and support mechanisms need to be reviewed in order to drive a faster renewable energy integration.

6.2 Integrating wind into the natural environment

Further research is needed to understand and mitigate potential effects of wind farms on birds, bats, and marine animals (offshore). Mitigation efforts can include the development of bird and bat deterrent systems that prevent avian animals from harmful interaction with wind turbines. Moreover the wind sector can improve its assessments on ecosystems and life cycle analysis.

6.3 Ensuring public engagement and acceptance

Social acceptance is a key component of successful wind energy projects. In addition to the consolidation of research on key aspects for public acceptance such as noise, further research is needed to understand the drivers of public engagement.

6.4 Human deployment

The wind power sector must further assess and specify its need for qualified human resources and skills in terms of engineers, scientists, experts and developers. More specifically, investigation on how to fill the gap in the O&M sector in the coming years would boost the development of the sector.

1. Grid systems, integration and infrastructure

The large-scale deployment of wind power not only entails solving challenges linked to the design, connection and operation of wind turbines and wind farms. It also entails the transformation of the design and operation of the electricity system. Wind energy will become a central element of the power system as forecasts see it covering between one quarter and one third of the demand by 2030. The question is no longer how the technology can meet grid connection requirements, or how to provide sufficient power to the grid, but rather how to manage effectively a system largely powered by wind and other renewable energy sources.

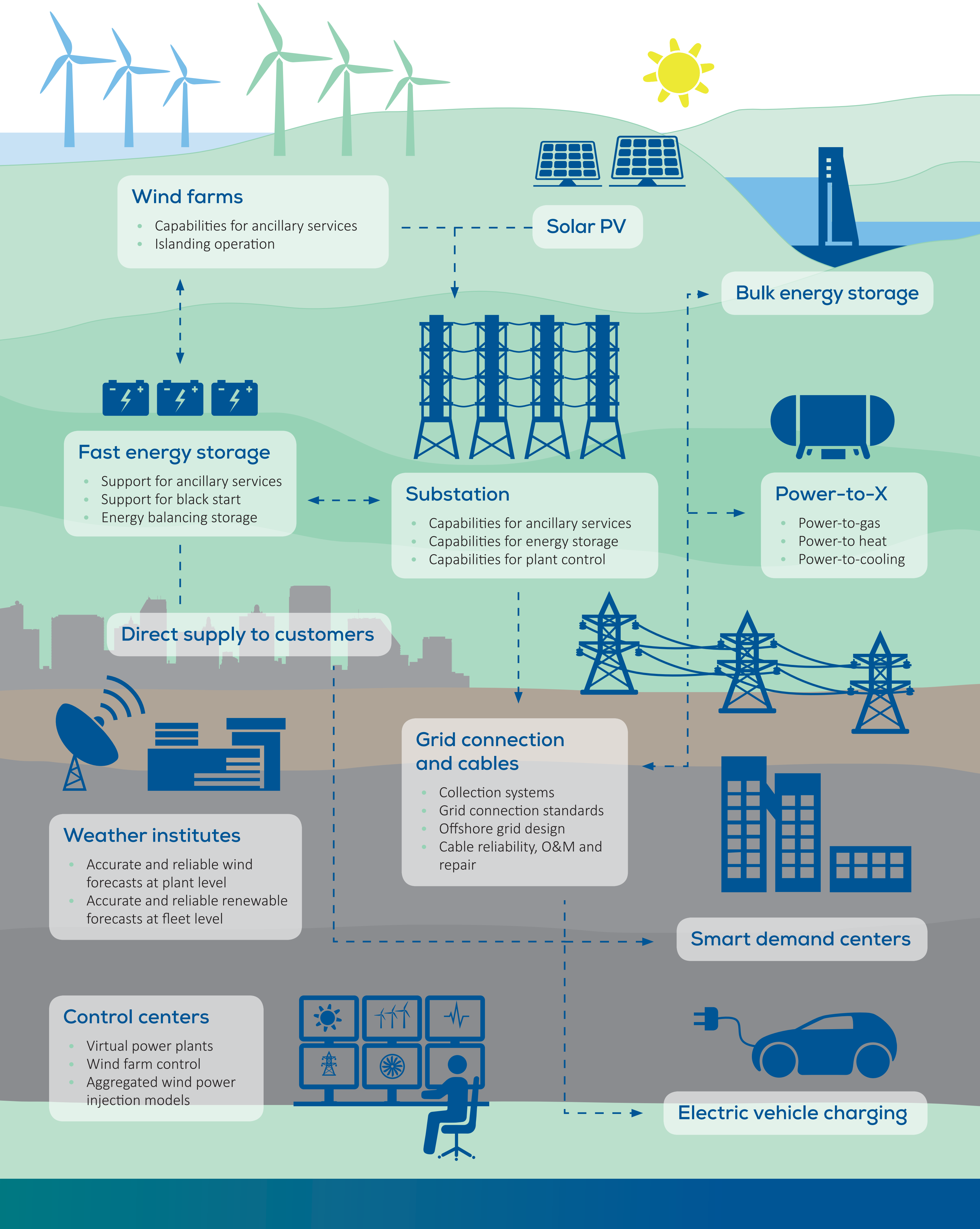
Research and innovation (R&I) therefore needs to address challenges related to controllability, energy management and communication of wind farms with grid operators and other assets in the power system. Furthermore, it is important to better exploit the technical capabilities of wind power plants to offer ancillary services, which conventional generation provided so far. To do so, grid code requirements and technical standards for these system services need to accompany the roll-out of testing facilities, where one can replicate real system conditions.

Research should also look at market design and regulatory aspects that ensure the system values these capabilities properly and that provide incentives to optimise their use. Investigating the role of energy storage technologies in this sense could offer some solutions. Finally, the design and build-out of future electricity grids that will collect and transmit power across large distances, in particular offshore, requires further research.

Key research priorities (not listed in order of priority) are:

- Grid integration solutions, including energy management and balancing with other renewable energy sources and remaining power plants;
- Control and architectures for the provision of ancillary services;
- Improved long distance transmission and collection systems; and
- System flexibility and energy storage.

FIGURE 2
Key research and innovation topics for grids



1.1 Grid integration solutions, including energy management and balancing with other renewable energy sources

Wind power has to be managed and balanced at a system level, taking into account other renewable sources, load peaks, and demand management systems as well as the constraints of the grid infrastructure and transmission capabilities. For this to take place, weather services, forecast institutes companies and universities need to develop more sophisticated tools to forecast, monitor and control wind farms energy output at the point of connection. Once a wind farm is "visible" and "controllable" at the point of connection, the next step is to effectively communicate and manage a group of wind farms or portfolio of generation assets to provide energy, power and system services, including balancing, when requested by the system operator. The design and operation of ancillary equipment, located at the plant's substation, should consider these capabilities too.

Relevant research priorities include:

- Wind farm management to the point of connection;
- Virtual power plants from physical to virtual point of connection;
- Enhanced smart substations ready to provide grid support functionalities, black start functionality and local services such as electrical vehicle (EV) charging; and
- Improved renewable power forecasting (plant and fleet level).

a. Wind farm management to the point of connection

Further research should also be made on concepts and standards for enhanced **communication, monitoring and control of wind farms** together with real-time analytical tools for decision-making. This would lead to improved wind farm management and a reduction in the cost of energy. Also, the development of technical capabilities to accurately reduce or increase a wind farm's power output (active and reactive power), based on a system operator's signal and available wind resource, is an essential enabler for wind power plants to contribute to balancing services.

b. Virtual power plants from physical to virtual point of connection

The optimisation of wind farm management should not only be at the power plant level but should also include a larger set of power generation units, which are not necessarily based at the same location. **Virtual power plants** allow energy ***aggregators*** to gather a portfolio of smaller generators and operate them as a unified and flexible resource in the energy market. The aggregation and control of virtual power plants reduces gradients and forecast errors of the power output and increases the capability to provide grid support services.

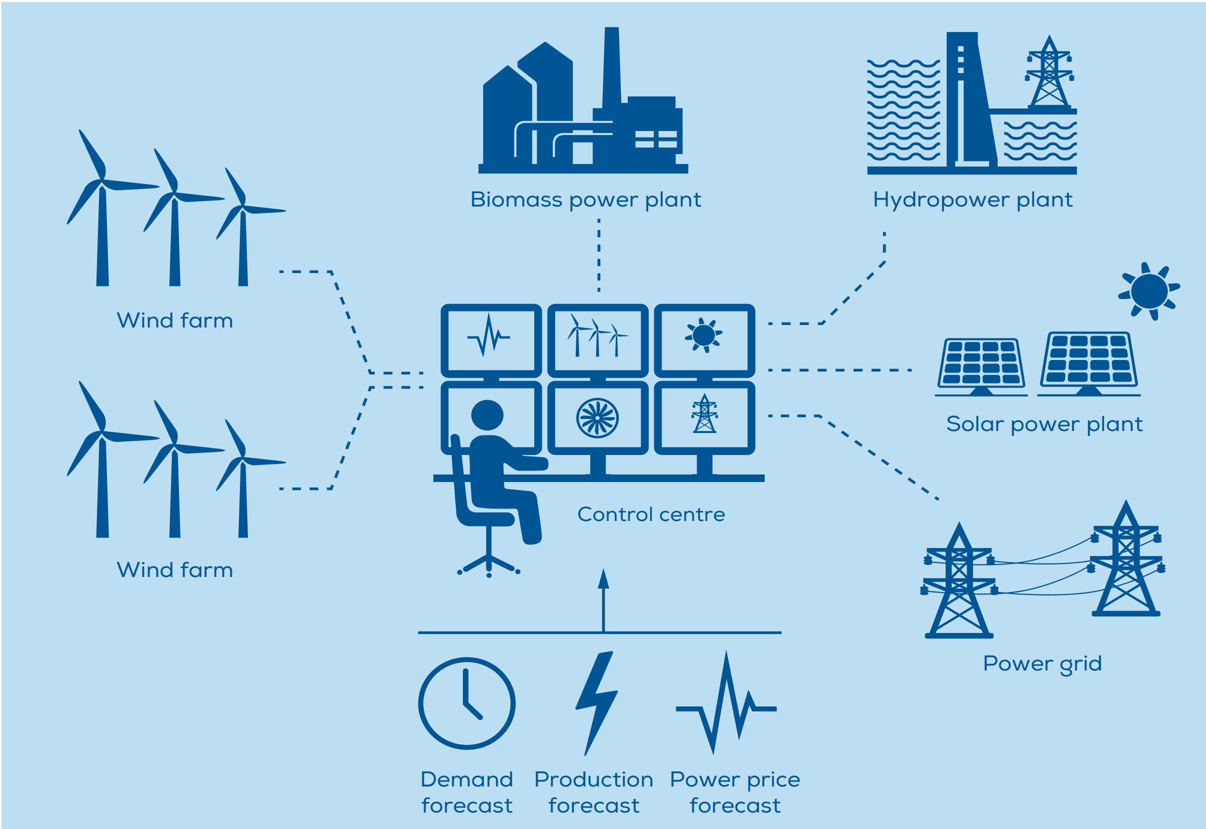
Research in this aspect comprises:

- **Real-time portfolio level optimisation** of energy resources (a shared functionality between participants in a virtual power plant depending on the local and system conditions, market prices and operators needs);
- The provision of **ancillary services through virtual power plants**; and
- Business models and solutions to regulatory challenges enabling the uptake of virtual power plants.

c. Enhanced smart substations ready to provide grid support functionalities, black start functionality and local services such as electrical vehicle (EV) charging

The substation is one of the most important components of the wind power plant. It represents the main point where one monitors, controls and transforms electricity to voltage levels suitable for transmission and distribution. Given the increasing contribution of distributed power generation and smart demand centres (electric vehicle recharging points), substations will need to cope with an increasing amount of fluctuating power which may affect both voltage and frequency of the grid. They may also be called on to facilitate black start and stand-alone operations by hosting storage and control devices. They may also host charging facilities for electrical vehicles in the near future.

FIGURE 3
An example of virtual power plant for Next Kraftwerke[10]



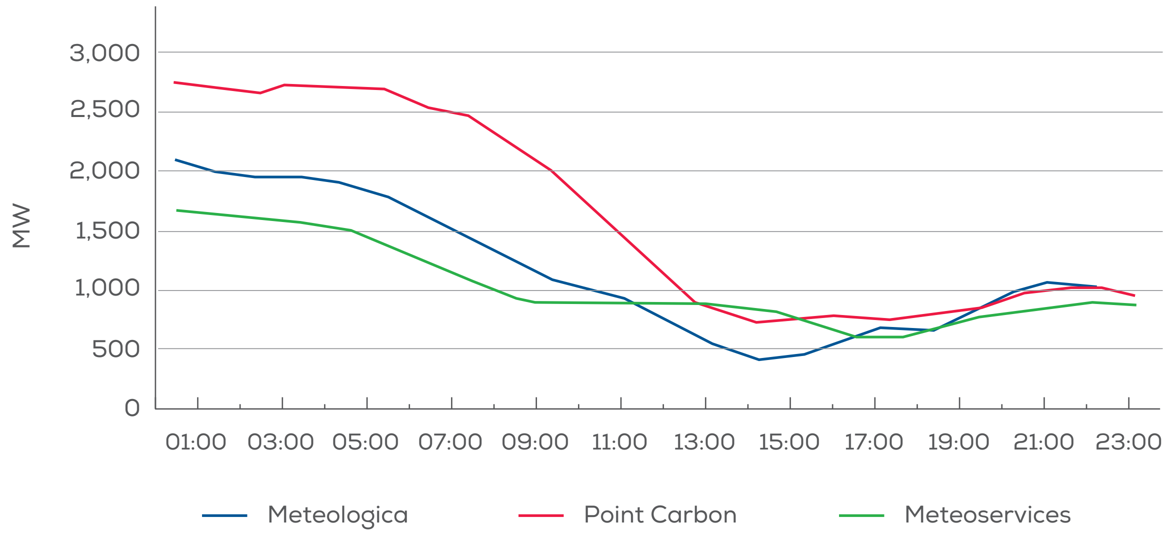
There is a need to research how the design of substations could contribute to further reduce the cost of wind power and other renewables, for example by hosting reactive power capabilities, fast energy storage devices, plant controls and automation devices. Developing technical capabilities further could lead smart substations interact with weather conditions, grid faults and cybersecurity threats. Business models and solutions to regulatory challenges also deserve a closer look, enabling the uptake of these technologies.

d. Improved power forecasting

As wind power system operators are increasingly exposed to market participation and becoming balancing providers, the ability to forecast wind power accurately becomes more important than ever. Consequently, the industry needs to further develop enhanced, more accurate and reliable forecasts at fleet, electrical grid node and regional level. Cooperation between weather services and power forecast providers helps get the best possible forecasts. The future forecasting methods have to consider explicit measures for reducing power generation that are not primarily weather-dependent. Among these are models and systems for sharing local wind farm data without compromising individual commercial interests. Probabilistic forecasts and procedures to apply them in decision-making processes can help cope with forecast uncertainties.

10. Virtual plant for Next Kraftwerke, ABB

FIGURE 4
Day-ahead forecasts of wind generation in Poland from different providers. Increasing the accuracy of these forecasts would decrease the need to balance excess or shortage of wind power in the system



1.2 Control and design of turbines and wind farms for the provision of ancillary services

One of the main areas for research is the capability of wind power to provide ancillary services and the right market design to procure, use and value these services. As a first step, one also has to identify the necessary ancillary services that have to be implemented in the respective codes. The following questions are pending:

- What are the necessary ancillary services provided by renewable energies?
- How can renewables interact with ancillary services provided by conventional power plants?

This may include research on voltage and frequency support to the grid in the short term and **capabilities for new ancillary services, such as synthetic inertia, islanding operation, black start capability, and fast reactive fault current provision** in the medium term.

Common definitions of the power system's physical needs remain key for manufacturers and researchers to develop solutions that are technology neutral and that support system stability.

Research should also focus on optimising the provision of functionalities all levels, from the turbine to the farm and even at cluster level. For instance, a cluster of wind turbines could work in close cooperation to control voltage stability at the same network node, reducing significantly the cost of equipment for each individual plant. Once again, politicians and regulators need to address the regulatory framework (e.g. grid codes) to enable solutions for common and aggregated system services.

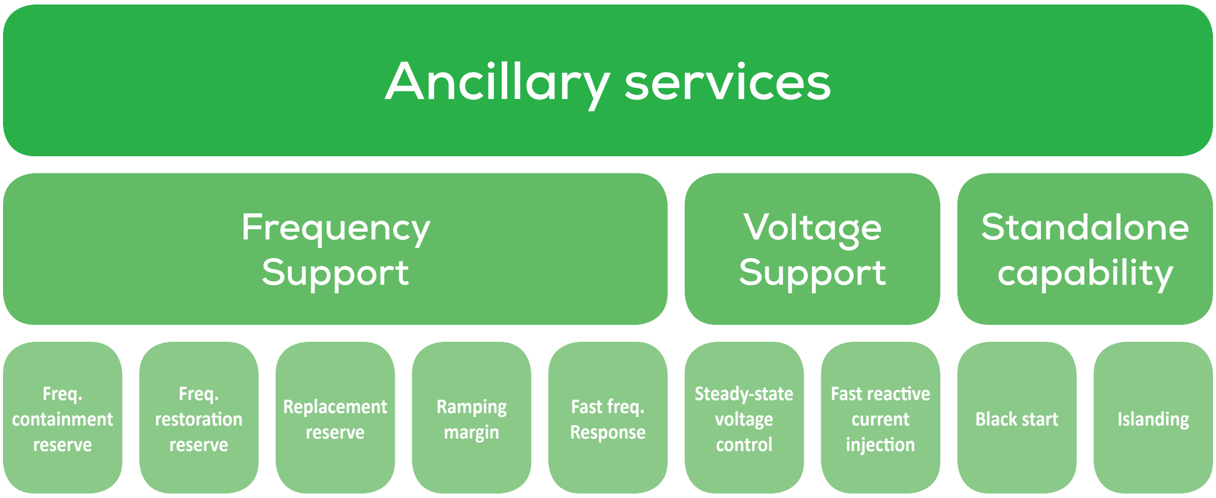
Research in the area of ancillary services should be forward-looking and open to new grid models and move away from the business-as-usual scenario because the grid is changing in function, size, control and impact.

a. Voltage support

Given frequent extreme climate phenomena and the increasing amount of electricity coming from renewable sources, voltage management needs to improve in terms of function, reaction time and control. Further development has to happen for electrical devices such as **static synchronous compensator (STATCOM) and capacitor banks** that enable to both keep the voltage

FIGURE 5

Three-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[11]



steady and smoothen out instantaneous active power fluctuations. The ability of electrical devices to control reactive power, limit grid impedance, and improve the power output of the wind farm needs to improve. A stable grid voltage will improve the power transmission, since the transfer of power depends on the system voltage, decreasing the long-term cost of the turbine. R&I also needs to lay out how renewables can provide the mentioned functionalities.

The future development of these devices has to accompany **testing, verification and operation in new ways, leading to the delivery of standardised products** that can meet the needs of network operators and producers and the grid stability demanded by end-users.

b. Frequency support

Fast and large frequency variations occur for a variety of reasons and can also happen due to the lack of inertia in a system, especially when relating to offshore wind plants. Control capabilities and new software strategies have to develop in order to enable wind power to contribute to system stability, through the provision of primary and secondary frequency reserves, damping frequency oscillations and synthetic inertia.

Power systems models will need further development. They should be able to **model aggregated wind power injection** from many different sites and with cognisance of other technologies, and improve the understanding of the cost and value of frequency support by wind, in a reliable and robust way.

The industry should work closely with system operators to further define system needs. One could develop new market products at turbine and plant level that could then reflect these needs (e.g. fast frequency response). It is worth exploring the need for synthetic inertia and boundaries with fast frequency response. Here, we have to re-assess the role of virtual power plants in supporting islanding operation and black start.

c. Standalone generation and black start capabilities

Greater standalone capabilities will be needed in a grid that is more regionalised and needs increased self healing and standalone capability especially when large storm damage and flooding continue to increase. Due to the growing importance of wind power and solar PV, they must have the ability to produce and deliver electricity in an **autonomous mode (islanding operation)**.

11. REservicesS Project

Currently, only a small number of wind power systems are able to black start when the grid is down. Research should investigate how wind - in cooperation with other grid actors - can contribute to the **system partially or totally restore itself after a blackout**, thereby focusing on methods of reliable participation by wind power plants in power grid start up processes.

d. Grid codes, standardisation and testing facilities

Once technical capabilities emerge, you need to test them in real time, verify them independently and then standardise them to allow grid operators to easily manage grid services from wind power. It is vital that these services are seen as an integral part of the grid and not a bolt-on solution that would eliminate potential synergies with the footprint of the other technologies active on the grid.

Management, analytical and information models are thus vital for enabling Europe-wide wind grid connection standardisation.

Finally, grid connection standards are key to ensuring technology robustness and common approaches to grid integration, progress towards harmonisation and future cost reductions. Grid connection codes in Europe are undergoing significant changes[12], led by European efforts to strengthen cross-border trade and maintain security in a system increasingly dominated by converter-based technologies. The development of standards to verify technology capabilities needs to be accompanied by the rollout of testing facilities where one can replicate real system conditions.

In any case, we should closely align R&I on grid code implementation of ancillary service provision with relevant system operators or associations (e.g. ENTSO-E) and keep in touch with dedicated R&I establishments. System operator associations[13] have identified research demand within the categories:

- Grid architecture;
- Power technologies;
- Network operation;
- Market designs;
- Asset management; and
- Joint TSO/DSO R&D activities.

This will allow for further cooperation in the context of grid code development and definition. The development of standards for verifying the technology capabilities needs to be accompanied by the roll out of testing facilities where real system conditions can be replicated.

1.3 Improved transmission systems including their operation and maintenance

Grid connection is the most important single variable for any generation technology. To ensure that the continued decline in the cost of wind power is not hindered by grid constraints, we need a pan-European roadmap for developing the electricity grid, based on ENTSO-E's "Ten Year Network Development Plan (TYNDP)". This should comprise the collection of wind power from onshore or offshore sites as well as the process of conditioning, transmitting and storing it. Relevant research priorities are:

- Offshore grid design including a multi-node multinational connection system to reduce the chance of export cable loss;
- Wind farm collection systems; and
- Reliability of cables and substations.

a. Offshore grid design

Grid connection accounts for an important share in the total investment cost of an offshore wind project. R&I has to aim at reducing this cost and ensuring greater reliability of the interconnections. The industry should further explore new concepts for offshore grid connection given that subsea cable technology has remained unchanged for many years. More progress has to happen on offshore HVDC connection systems research (i.e. reducing the cost and complexity of VSC/HVDC connections) to drive down their cost and to improve their reliability. China has made great strides in the development of an effective HVDC onshore system to deliver energy effectively from low-populated generation areas to urban and industrial load centres with high demand.

We also have to consider **meshed grids** in order to reduce cost and increase reliability of offshore wind power connections. **Hybrid AC/DC** solutions are worth exploring,

12. See http://networkcodes.entsoe.eu
13. Entso-e Research & development roadmap 2013-2022.

technically and economically. In addition, we have to investigate how to **enhance better regulatory compatibility between countries** that need to connect. Standardisation for offshore cables can help here reduce costs (i.e. standards for dynamic cable rating, connections, materials,...).

b. Wind farm array and delivery systems

The collection grid begins with transformers at each wind turbine. It needs to step up from the generation voltage, typically 690 V, to a medium voltage of typically 25–40 kV. Wind farm array and delivery systems can improve through the coordination of the entire electrical chain from the turbine to the transmission grid. We have to investigate how new collector grids could collect more power because this could lead to significant savings on investment costs and electrical losses.

c. Reliability of cables and substations

In 2015, two large offshore wind farms went offline due to cable faults[14]. The development of condition monitoring systems for cables and substations will trigger the deployment of new maintenance strategies for these components and allow fault mitigation in advance. This will increase the availability of wind power and reduce costs at the operation and maintenance level.

1.4 System flexibility and energy storage

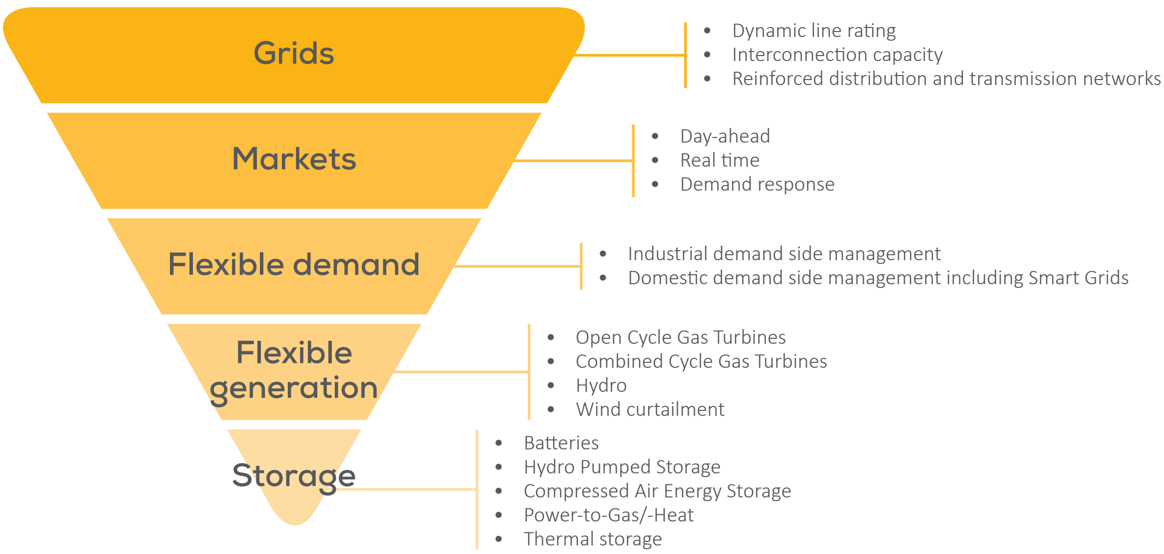
Energy storage could play an important role in wind development because it could smooth the variability of all power generation and supply more economically the grid.

Today, the cost of energy storage is higher than other alternatives of system flexibility. Energy storage will need to become more efficient before industrialised large-scale seasonal storage facilities break through. However, energy storage could already contribute today to support wind power integration in certain applications. In particular fast energy storage can help with frequency and voltage support as well as on correcting energy imbalances.

Research priorities include:
- Support of wind for ancillary services;
- Development on energy balancing storage; and
- Development of bulk energy storage.

Other areas of interest include:
- Development of low cost high-cycle and long-life utility grade batteries;
- Analysis on the type and location of storage technologies in the grid and studies on governance to control them;
- Analysis of short-, medium- and long-term storage technologies; and
- Ownership and payment models.

FIGURE 6
Sources of flexibility



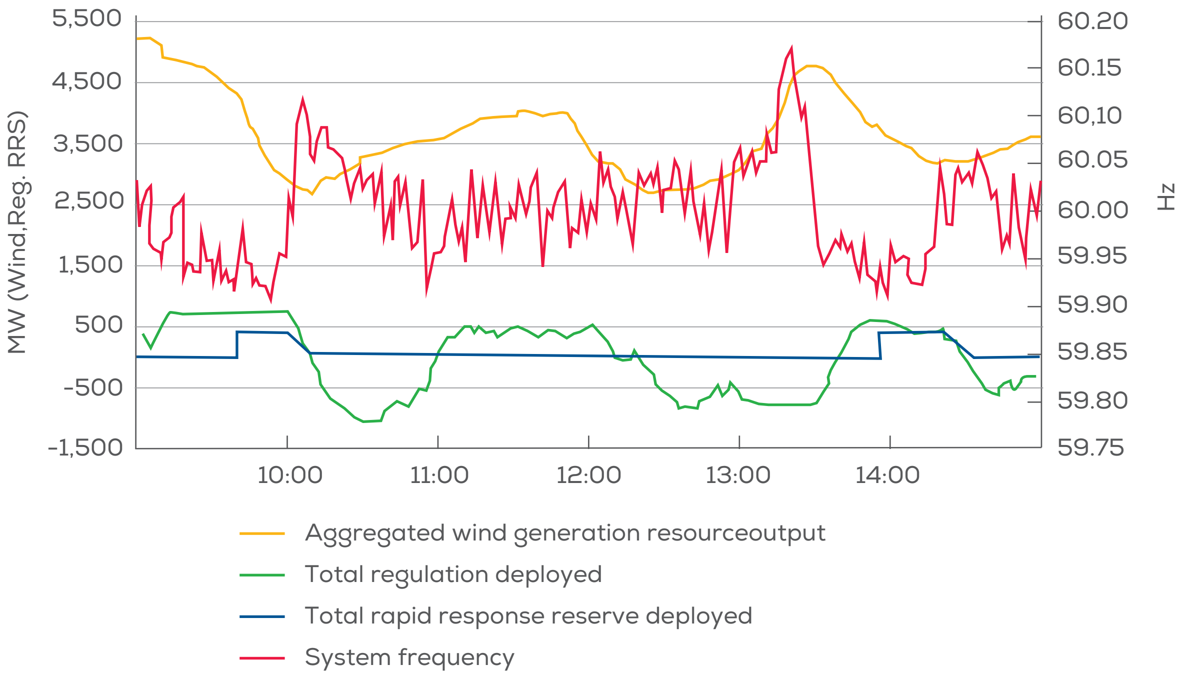
14. Anholt (400 MW) was offline in February 2015 for four weeks and Horns Rev 2 (209 MW) was offline for 5 weeks in October 2015 due to unscheduled cable faults.

a. Support for ancillary services and black start capabilities

Energy storage and more specifically battery storage is well suited to a range of ancillary services on short-term regulation or frequency/primary response. The ability of batteries to respond faster than power plants makes them an ideal complement to wind energy in order to provide these power services. We require more research to better understand and test how energy storage and wind power can provide services together.

FIGURE 7

Deployment of energy storage primary reserve according to wind fluctuation in Texas[15]



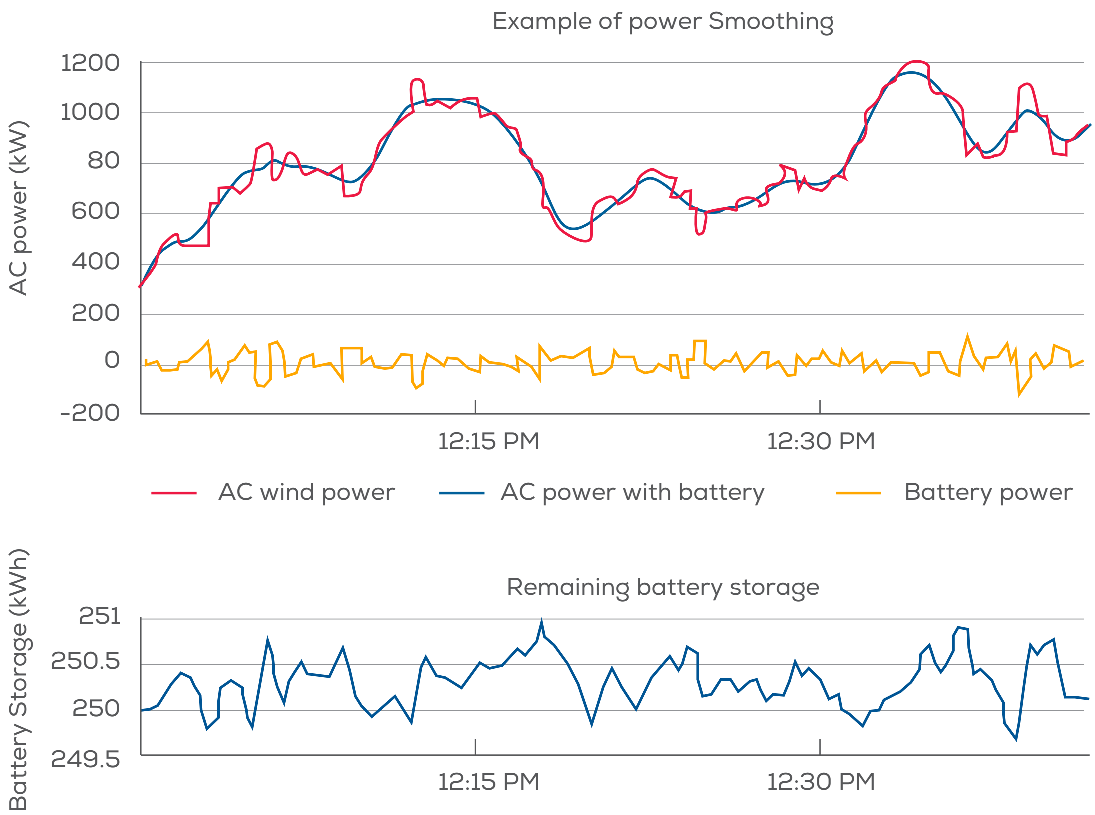
15. Eto et Al., 2010

b. Development of energy balancing storage

Using energy storage to balance wind power variability would help producers decrease their balancing costs and also help the integration of variable generation into the power system. Very short-term charging and de-charging modes reduce battery lifetime considerably. The cost and value of energy balancing storage requires additional analysis.

FIGURE 8

Power output smoothing in order to balance wind generation[16]



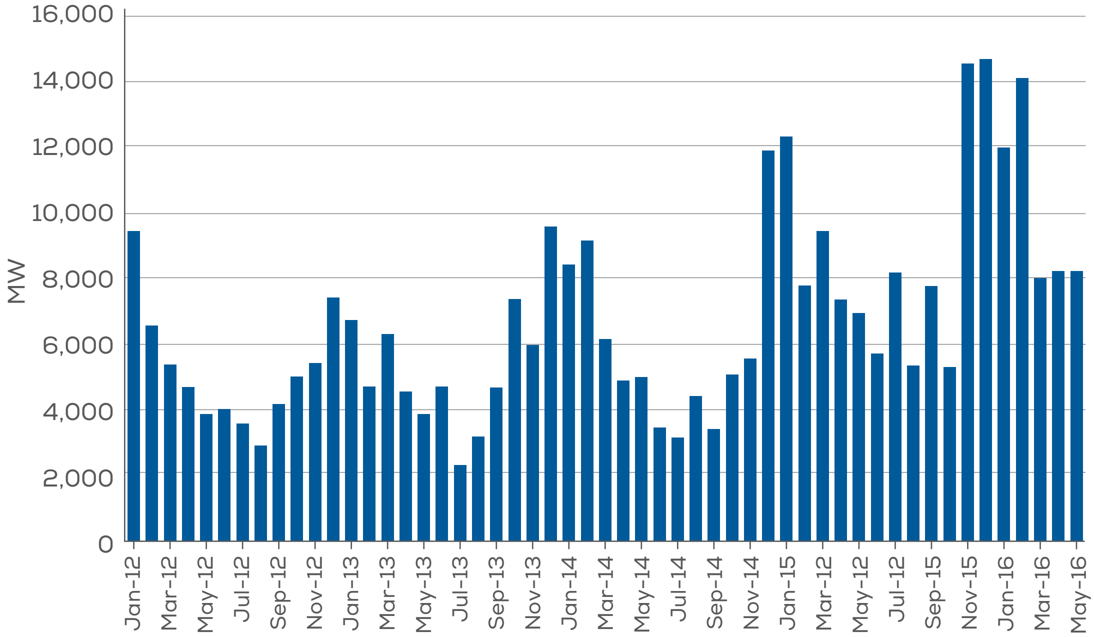
16. Johnson et Al., 2011

c. Bulk energy storage and coupling with gas and heat

Bulk energy storage could enable wind power to take advantage of periodic generation and load patterns (daily, weekly, seasonal, yearly) by storing a surplus and using it at low wind generation periods. In the long term (post-2030), research should aim to launch coupled actions between wind power and bulk storage in order to further increase wind power integration. The understanding of seasonal wind patterns remains essential to develop the technology properly. The main technology that currently fulfils this role is pumped-storage hydro power. Compressed air energy storage, power-to-gas and power-to-heat/cooling might become options in the future.

FIGURE 9

Monthly wind profiles in Germany[17]



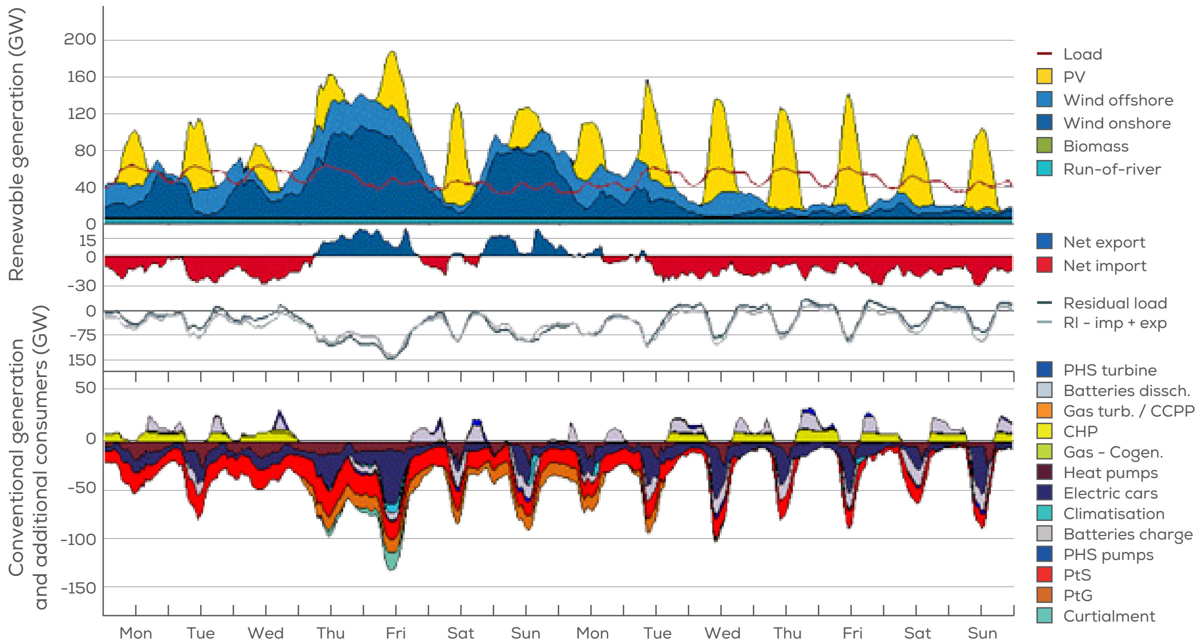
17. EEX Database

d. Increased system flexibility by sector coupling

The massive coupling of the energy sectors (transport, heat and electricity) will reduce imbalances in the electricity sector and increase the flexibility of the entire energy supply system. Regional energy balancing by sector coupling will reduce curtailment of wind and solar power and lead to a better utilisation of the electricity grid. Furthermore, wind and solar power will substitute the use of oil and gas in the heating and transport sectors.

FIGURE 10

Renewable energy production and demand forecast in 2050 in Germany[18]



18. InteraktionEE-Strom, Wärme und verkehr, Fraunhofer, 2015, the scenario used comprises a GHG reduction of 83%, a high share of E-mobility, a net growth in electricity demand from 557 TWh in 2015 to 793 TWh in 2050 and installed capacities of PV onshore wind and offshore wind at respectively 200 GW, 140 GW and 38 GW.

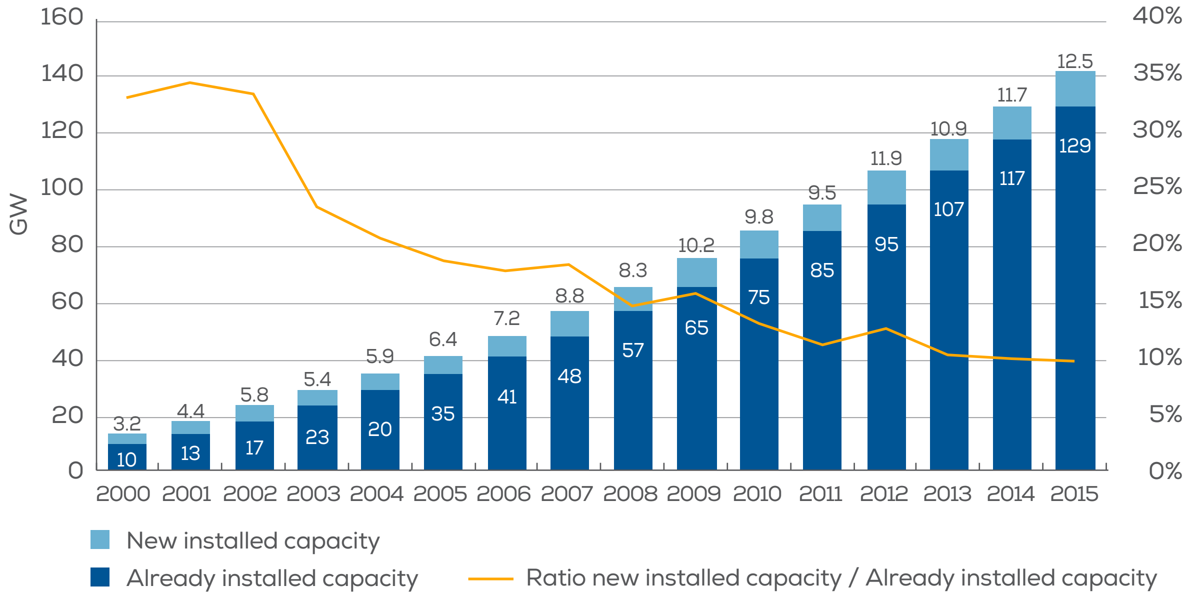
2. Operation and maintenance

By the end of 2015, total wind power installed in Europe reached 142 GW[19] and was the third biggest power generation in terms of installed capacity with 15.6% of the total EU capacity mix. The share of wind power in the system is increasing at a fast pace and annual new installations are a decreasing share of cumulative installed capacity. In 2015 the 12.8 GW of new capacity accounted for less than 10% of the total installed capacity.

Wind energy research and innovation traditionally focused on new wind turbine design and technology development. The growing amount of operating capacity today highlights the need to devote more efforts to the operation and maintenance of wind farms.

FIGURE 11

Installed capacity of wind power in the European Union[20]



19. Wind in power: 2014 European statistics, WindEurope, 2015
20. WindEurope Statistics, 2016

The data available on operating wind turbines has never been so voluminous as it is today. Industry requires significant research and innovation to properly analyse and treat such wealth of information in a way that serves its cost reduction targets.

Wind operators will need to capture and store an increasing amount of data through the improvement of methods and the design of upgraded or new sensors. More advanced sensors and an increased number at different locations of the turbine will make this possible.

The industry can improve reliability, predictability and energy yields through the use of this data in O&M processes by enhancing diagnostics and taking better operational decisions. Also, optimisation of residual lifetime such as lifetime extension and repowering will play an increasingly relevant role given the high number of turbines getting closer to their technical end of life. To exploit these benefits, wind energy players will have to improve data sharing without compromising confidentiality of the individual operator.

The main research priorites are:

- Standardised and validated methods using improved sensor systems for performance measurement and condition monitoring;
- Improvements in energy yield from wind farms through the development of real time testing and utilisation of adaptive and interactive technologies and big data control;
- Improvements in reliability and predictability of wind farms and data analysis to improve diagnostics and decision-making; and
- Lifetime optimisation and life extension of wind turbine systems.

2.1 Standardised validated sensor systems for performance measurement and condition monitoring

An increase in the number, quality and robustness of sensors is crucial to obtain more accurate sets of data to better understand wind turbine operation and component performance. Further research into standardisation of sensors and applications will help to reduce costs.

Sensor reliability could improve through research into increased protection and redundancy, which should be considered as a parallel solution. Operational solutions such as self-diagnostic systems and multi-sensor constructions also deserve further investigatation. Finally, improving speed and efficiency of data transmission from **wireless solutions** will need further research.

In parallel, wind energy R&I will need to develop **new enhanced sensors for condition monitoring**. They will monitor the evolution of key areas of the turbine such as grouted connections especially for offshore turbines, joint failures, electrical systems, fatigue crack initiation and propagation, cyclic degradation and marine growth and structural health in submerged areas. Additionally, the industry would benefit from standardisation and new added capabilities for condition monitoring systems both in turbines and structures.

Further improvements in the use of **remote inspection** will balance the trade-offs between the use of condition monitoring systems, remote operated vehicles, drones or human inspection of wind turbines for maintenance purposes.

The development of **new sensors for external conditions integrated within the control systems** is fundamental to taking advantage of the close environment of the turbine for improved energy yields and failure prediction, in a cost-efficient way. New standards for power curve assessment based on new measurement technologies (i.e. LIDAR) will help develop the technology further.

R&I should also focus on sensors that monitor inflow and external conditions. LIDAR and radar technologies, which have already proved to have an important potential for inflow measurements, require research individually and perhaps as intertwined units.

R&I should investigate in parallel the possibility to **standardise sensors and performance testing of similar models with other industries to learn how to adapt workable models to the wind energy industry**.

We will have to document the knowledge on materials in order to standardise the condition monitoring and maintenance processes.

2.2 Realtime testing, adaptive, interactive technologies and big data control to improve energy yield

The data collected by enhanced health monitoring and external condition sensors will open up fields of possibilities for improvements in energy yield at wind turbine, wind farm and clusters levels.

The aviation and equipment industries are very advanced in their data analytics models that link real-time performance to actual weather conditions, working hours of parts and planned and unplanned maintenance to optimise the performance of their fleet. Wind energy can learn from the models these industries have in place and adapt and fine-tune them for use in the wind industry.

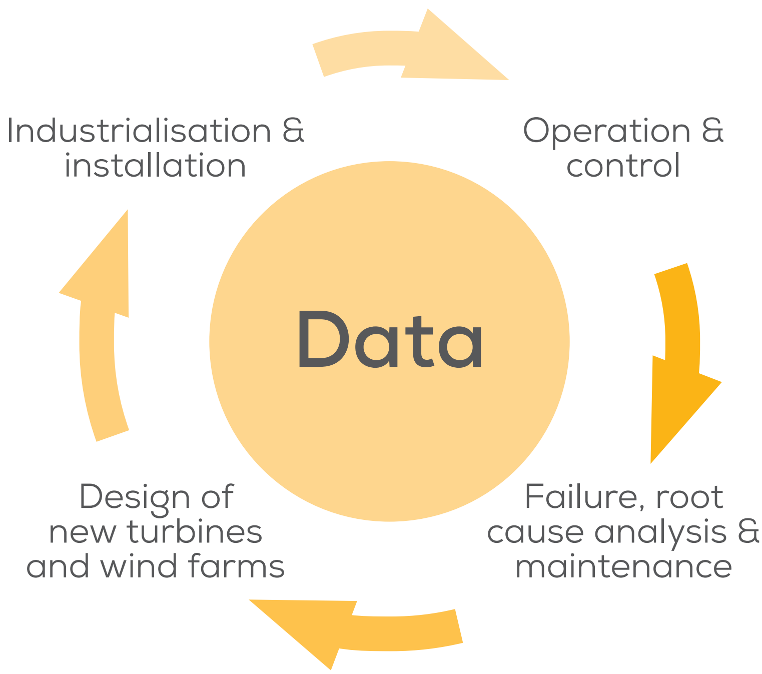
Wind energy R&I will need to investigate the **integration of condition monitoring systems, remote monitoring systems and SCADA information, into big data analysis tools to recognise important patterns in large data subsets to initiate critical improvements in operation and maintenance of wind energy assets**. Research efforts should be devoted to new conceptual expert systems that automate data processing and provide analysis to enhance decision-making. The development of data collection and analysis techniques is needed to pave the way for efficient understanding and use of wind turbine measurements.

The analysis of the data will make it possible for wind turbines to achieve improved energy yields through the reduction of downtime. The development of maintenance and control strategies will need to be investigated.

With regard to offshore wind, **the analysis of the metocean data with operational information** should provide results on the impact of external marine conditions on cumulative fatigue and life damage of materials and components.

The proper analysis of the O&M **data should help in the design of new turbines**. The better understanding of failure reasons and performance evolutions should drive new concepts and technologies (see figure below). New designs and concepts will need further decision-making models, comparing CAPEX and OPEX, and lead to cost reduction. **Real-time testing of new academic models** is vital to reducing the chances of bugs and failures in serially produced machines going forward.

FIGURE 12
Virtuous circle of wind turbine improvement through data



Wind R&I will need to investigate how stakeholders can share and aggregate their O&M data to collectively benefit from operational experiences and to increase the statistical robustness of analyses.

Ultimately, models need to be developed that combine O&M data with real-time energy prices in order to optimise energy yields and revenues.

2.3 Tools for data analysis, diagnosis and O&M strategies to improve reliability and predictability of failures

The data available should also make it possible to gather knowledge on the evolution of components and materials during the lifetime of the wind turbine. This should then enable operators to increase the reliability and predictability of their plants, realise better diagnostics and improve the quality of decision-making. A clear distinction has to be made between failures due to badly produced components and badly designed components, to focus R&I on the design of better components.

Wind energy players will need to focus R&I on understanding and better monitoring wind turbine structures, crack initiation and growth prediction. The data about structural health should provide the information needed to identify failures and launch predictive maintenance. We should consider the same approach for the components of the turbine, for example, which failures can be anticipated. Wind energy R&I needs to carry out the corresponding data analysis.

Better prediction and mitigation will allow the better optimisation of materials used in wind turbine structures and reduce the cost of post-commissioning repair dramatically.

With real statistical knowledge of the failure events and their context, we can implement condition- and risk-based maintenance strategies. R&I needs to focus on the development of these strategies and assess their efficiency and cost reduction potential. A continuous improvement should come from constant feedback from people in the field.

Wind energy R&I needs to assess the structural design based on advance modelling. These models need to be tested in real time field operations and run through intensive case study modelling to rule out the ones that are too expensive to be implemented going forward.

The larger the number of components, the larger the risk of failures. Concepts with fewer components and a simplification and standardisation of systems such as auxiliary systems will need investigation. In addition, the industry has to develop easy replacement of components for remote or difficult access through new spare design and robotic access technologies, applied to vessels or transfer systems. Finally, improved access systems for offshore wind and improved offshore access safety through technology innovation are points to be analysed.

2.4 Lifetime optimisation

As the wind energy market is maturing, operators are increasingly looking to enhance returns by managing their assets more effectively. Over the design period of a wind farm, R&I needs to identify and quantify the cost of improvements that can make a difference for its financial performance.

Lifetime fatigue analysis needs to be better understood, especially in regard to life extension. Measurement techniques should provide relevant data on fatigue, remaining life and failure mechanisms. Failure warnings allowing mitigation of structural failure in time will provide more safety for the units.

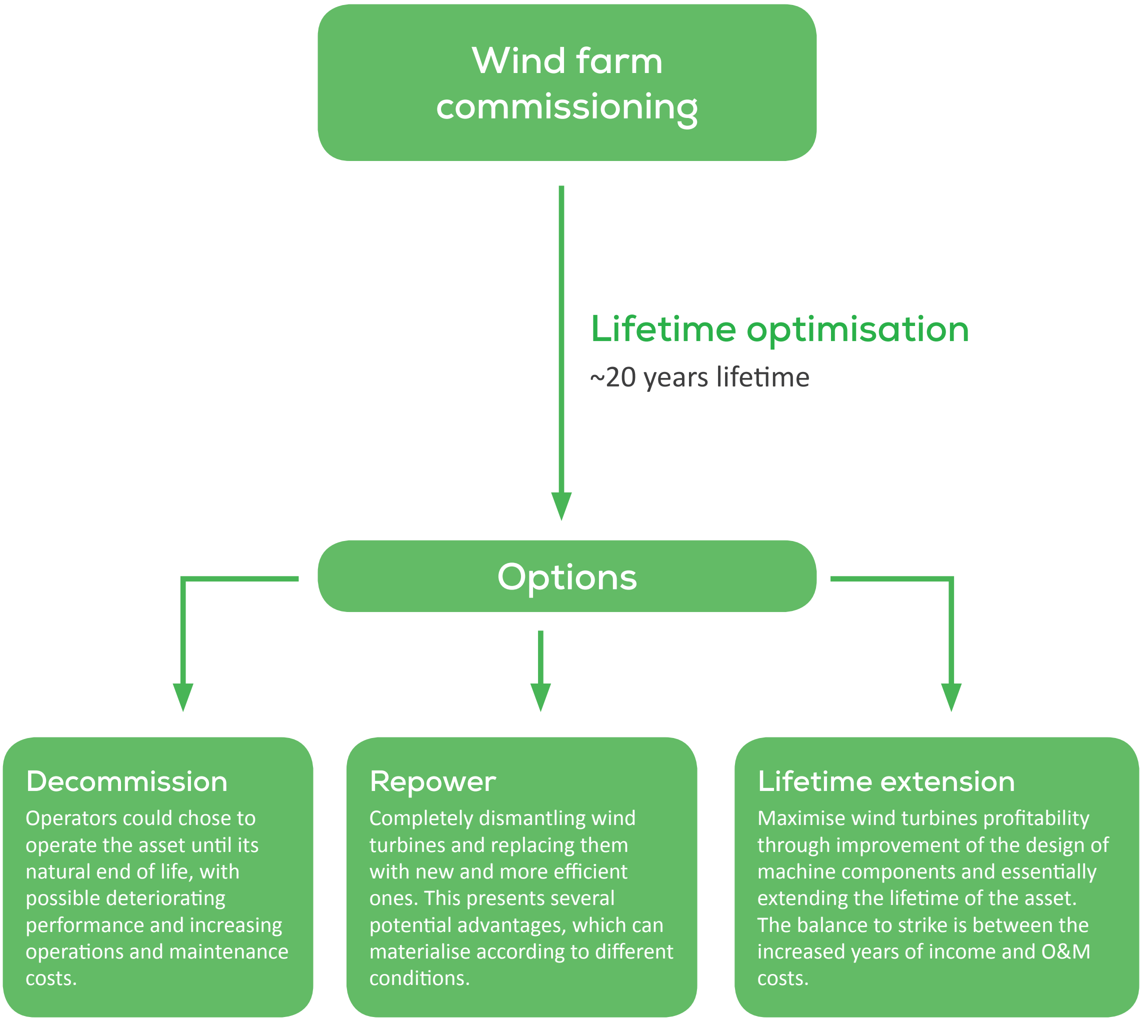
Rotor blade erosion also needs more investigation. R&I needs to define the measures to be taken to reduce the costs associated with blade maintenance. In addition, the point in the life of a blade when the leading edge requires replacement needs to be determined more clearly and methods developed to replace it economically. Testing can also increase the potential lifetime of the turbine.

Deploying lifetime extension projects needs to happen first before being able to routinely validate the extension of the lifetime of turbines. The actual service life of turbines shoud feedback for assessing the design life of future projects.

Researching the decision-making process at the end of a turbine's lifetime also stays on the agenda, for example, through assessing and comparing different end of life strategies. These strategies include life extension, repowering, decommissioning and multi-use of turbine for environmental monitoring or supply of emergency power in a standalone mode.

Another side of lifetime optimisation is the increased incidence of extreme weather events we are experiencing due to climate change. Prediction and mitigation models need to develop to a level that ensures turbines continue to operate in more extreme weather regimes, thus guaranteeing the owner's investment and ensuring wind power as a primary backbone of the European grid.

FIGURE 13
End-of-life strategies



3. Industrialisation

Industrialisation is one of the key enablers to reduce the cost of wind power over the short to medium term. It supports the development of a supply chain with a critical mass and common technical solutions. It also allows for significant economies of scale and faster delivery of products to the market.

As international competition is intensifying, Europe needs to keep its technological advantage in wind power and secure a continued success and economic contribution of its industry. It should invest heavily and continuously in key enabling concepts, technologies and innovative systems that will strengthen the whole value chain.

One precondition for fruitful industrialisation is that market volumes should be sufficient and visible for the short, medium and long term. This will allow stakeholders to make investments in all parts of the value chain including the R&I investments required to support industrialisation.

Relevant areas of research for industrialisation are:

- Standardisation;
- Regulatory market requirements and harmonisation; and
- Value chain development.

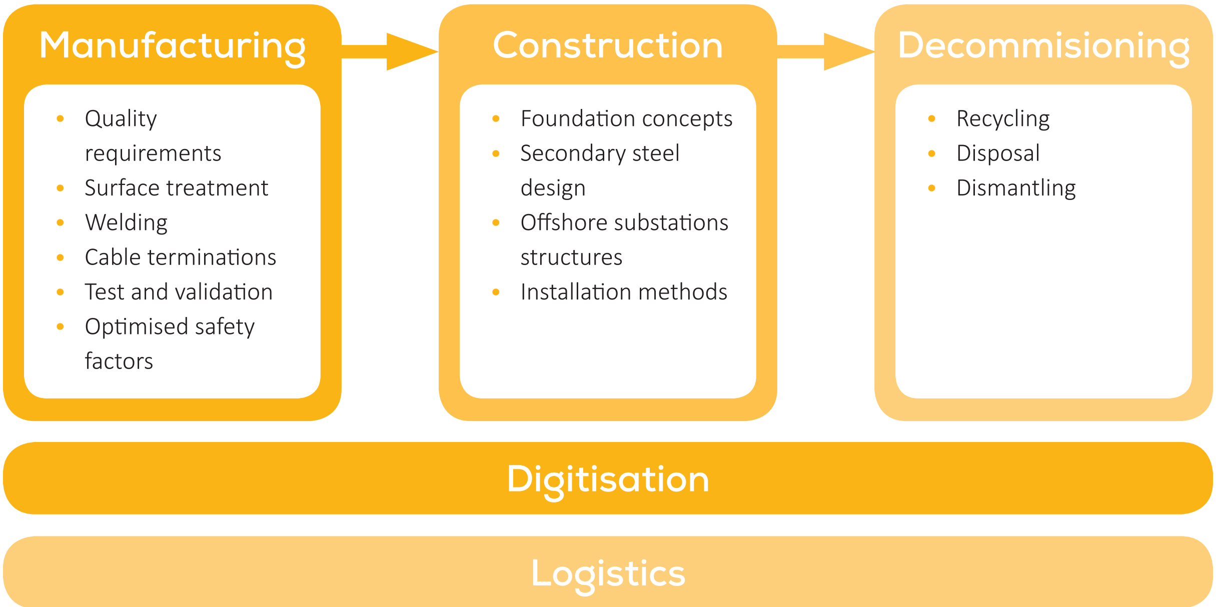
3.1 Standardisation

Historically, wind farms were separated engineering projects with the goal to optimise one project rather than multiple similar projects. Industry should take advantage of the similarities between projects to form a common basis of standardised components, methods and equipment, in order to introduce significant cost and time savings.

Standardisation should enable the same baseline concepts for different projects, independent of the developer, local authority or key suppliers to the projects. Specific site engineering will remain necessary to make the baseline concept fit the actual site, but the overall concept could be the same. Health and safety also benefits from standardisation by reducing variations in equipment and operations.

For example, in the case of offshore wind where co-operation over a number of projects reduces risk, optimises weather windows and reduces the number of repeated startup costs for projects.

FIGURE 14
Priority topics for standardisation



R&I needs to be focused on how it can enhance the standardisation of the following key enabling concepts and technologies.

At the manufacturing level, industry should define common standards on **quality requirements, surface treatment, welding and cable terminations** in order to favour better interactions between factories and develop common understanding and approaches to manufacturing and repairing processes. In addition, **testing and validation methods** (e.g. blade quality, and subsystems) can provide an identical basis for quality inspection. The definition of optimised safety factors for serial production could simplify safety codes and avoid over-engineering of components, thereby reducing costs.

Concerning materials and components of wind turbines, harmonisation can take place at the certification level, providing simpler and more uniform requirements. Design codes and standards can also apply to materials in order to help the industry work on similar quality levels.

Foundation concepts and secondary steel design represent a considerable cost for a wind power project (4-10% for onshore and 15-30% for offshore[21]). Today, it often happens that similar projects use different foundations.

Offshore substations structures and cables can benefit from well-thought standards, triggering higher cost savings.

Wind power R&I will need to investigate standardisation opportunities on **installation methods and logistics including equipment**. Important cost and time savings can happen at the construction and transport phase of projects.

The digitisation of the wind energy sector will trigger new communication interfaces between the different stakeholders of the value chain and the turbines. R&I should focus on how to organise this process in order to ensure that these interfaces transmit a standardised language.

With the aim to reduce the cost at the end-of-life, standardisation can also occur in sustainable recycling and disposal of turbines. Decommissioning is a relatively new practice with no established method or procedure for offshore foundations. Standardised methods for dismantling can contribute to reduce the cost of wind power and enable synergies between stakeholders. However, these will depend on the industry embracing standard support structures, especially offshore.

21. Renewable power generation costs in 2014, IRENA

3.2 Regulatory markets requirement and harmonisation

Common work methods and rules need to apply to regions as many of the future offshore wind farms will cover more than one jurisdiction.

Today, domestic and local authorities determine many different design requirements, leading to important additional project costs. Harmonising some market requirements as close as possible to the European level would enable a more efficient deployment of wind energy and increase the pace of its industrialisation.

Within the European Union, the different sea territories have different sets of rules and requirements for wind installations. This impacts time and cost of projects. R&I should work on defining and providing the most efficient and relevant solutions. For example, the wind industry would benefit from uniform helihoist platform design and from aviation and maritime signals. Proper design of offshore wind farm development areas will increase planning, and reduce tensions with current and future sea users such as shipping, pipeline owners, subsea mining companies.

Ultimately, the development of cross-licensing models for intellectual property will strengthen the future efficient supply chain and enable EU firms to benefit from non EU-innovations.

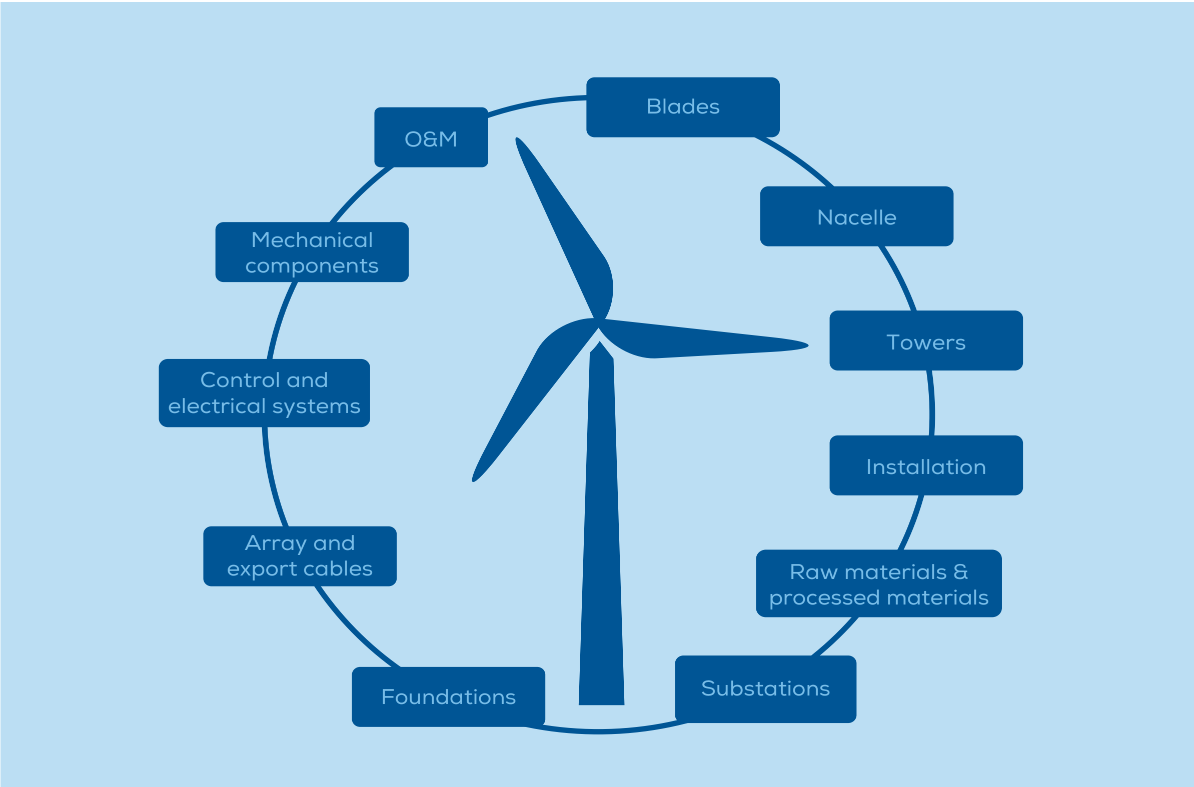
3.3 Value chain development

As part of the industrialisation process, the value chain development is key to ensure greater benefits and faster speed to market. An extended value chain cooperation between project developers and key vendors would further develop interoperability between systems, providing manufacturers with combined solutions. As unit sizes are increasing, they could benefit from additional optimisation. Focus should remain on identifying and supporting the EU value chain needs for new production technology.

R&I should focus on improved new materials such as steel, concrete, composite structures -including new forms of glass, conductors, high stress control electronics, welding technology, transport and erection technologies in order to find a right balance between lighter, cheaper, and stronger materials.

Improved measuring methods will allow for better interaction between stakeholders, providing a more accurate data along the value chain and avoid uncertainty caused by over-engineering.

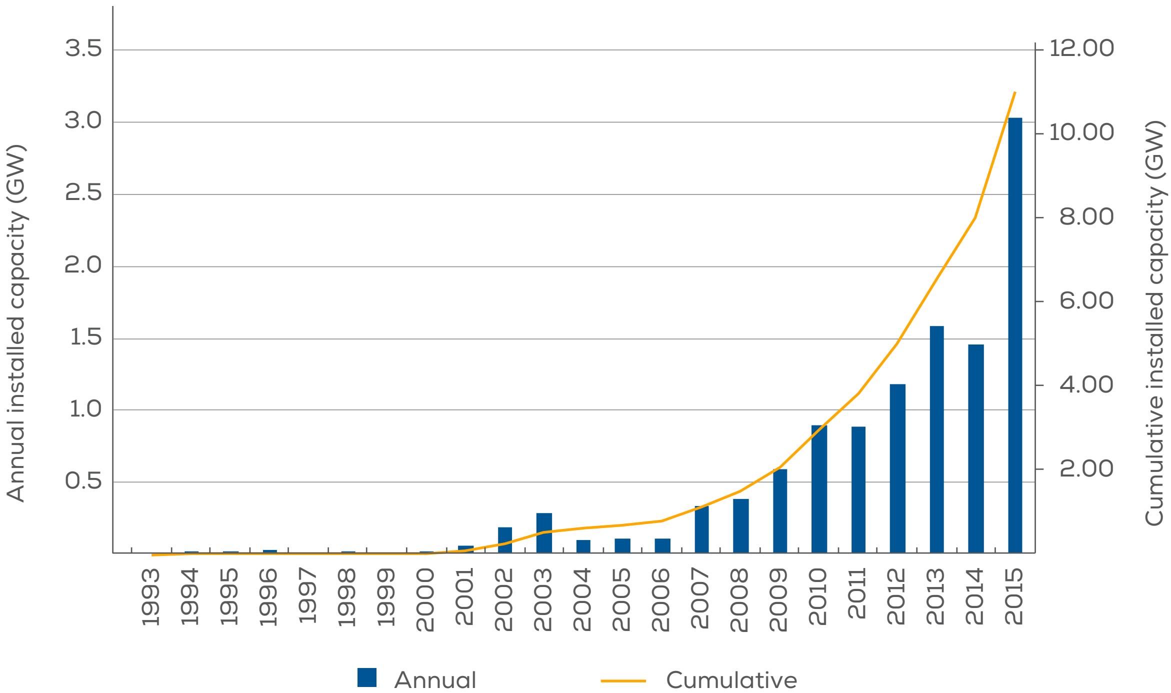
FIGURE 15
Wind power R&I can achieve better cooperation within the entire value chain



4. Offshore balance of plant

Offshore wind power has to play a crucial role in the European energy system. At the end of June 2016, 11.5 GW total installed offshore wind capacity was grid connected in the EU. On 6 June 2016, 11 leading companies committed to reduce the cost of offshore wind energy down to €80/MWh by 2025, highlighting the ambition of the industry to mature at a fast pace and become fully competitive with conventional generation.

FIGURE 16
The EU offshore wind market is growing at an increasing pace[22]



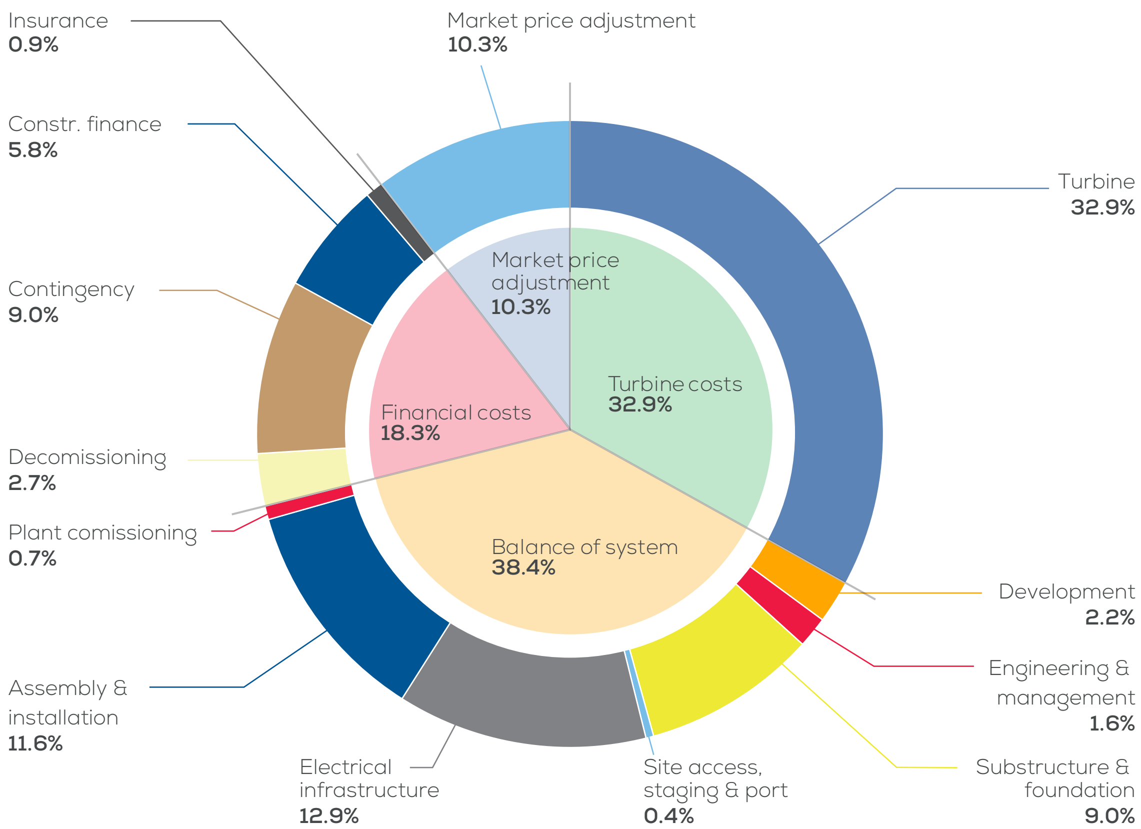
22. Annual statistics, WindEurope, 2016

The cost of offshore wind power is higher today than that of onshore, which in large part is due to the more expensive installation processes and higher associated O&M costs of working at sea. Offshore balance of plant includes the substructure and foundation, site access, offshore electrical infrastructure and assembly and installation, representing a significant proportion of costs for an offshore wind project[23]. R&I within the balance of plant needs to focus on continued cost reduction through large-scale infrastructure for research, development and demonstration.

Offshore balance of plant is also very sensitive to the plug in point as in some countries, such as Denmark most of the electrical infrastructure is the responsibility of the national grid operator.

On 6 June 2016, 11 leading offshore wind companies (Adwen, EDP Renewables, Eneco Energie, E.ON, GE Renewable Energy, Iberdrola Renovables, MHI Vestas Offshore Wind, RWE Innogy, Siemens Wind Power, Statoil and Vattenfall) underlined the crucial role of offshore wind by committing to reduce cost levels below €80/MWh for projects reaching final investment decision in 2025. Regional cooperation, stable regulation and long-term markets especially over the post-2020 environment were highlighted as the key enablers for reaching this target. Being restricted from making certain public statements due to applicable rules and regulation, Dong Energy was not a co-signatory of this statement. However, it remains fully committed to continue to reduce the cost of electricity in line with the rest of the industry.

FIGURE 17
Breakdown of the cost of offshore wind energy[24]



23. Cost of wind energy review, NREL, 2014
24. NREL 2014 cost of wind energy

This section addresses issues specifically related to offshore balance of plant. Five research topics have been prioritised:

- Industrialised transport and installation systems;
- Innovative and industrialised offshore towers and foundations, including better seabed interaction;
- Floating offshore wind farms;
- Innovative and industrialised offshore substations and cables; and
- Wind farm level optimisation and modelling.

4.1 Industrialised transport and installation systems

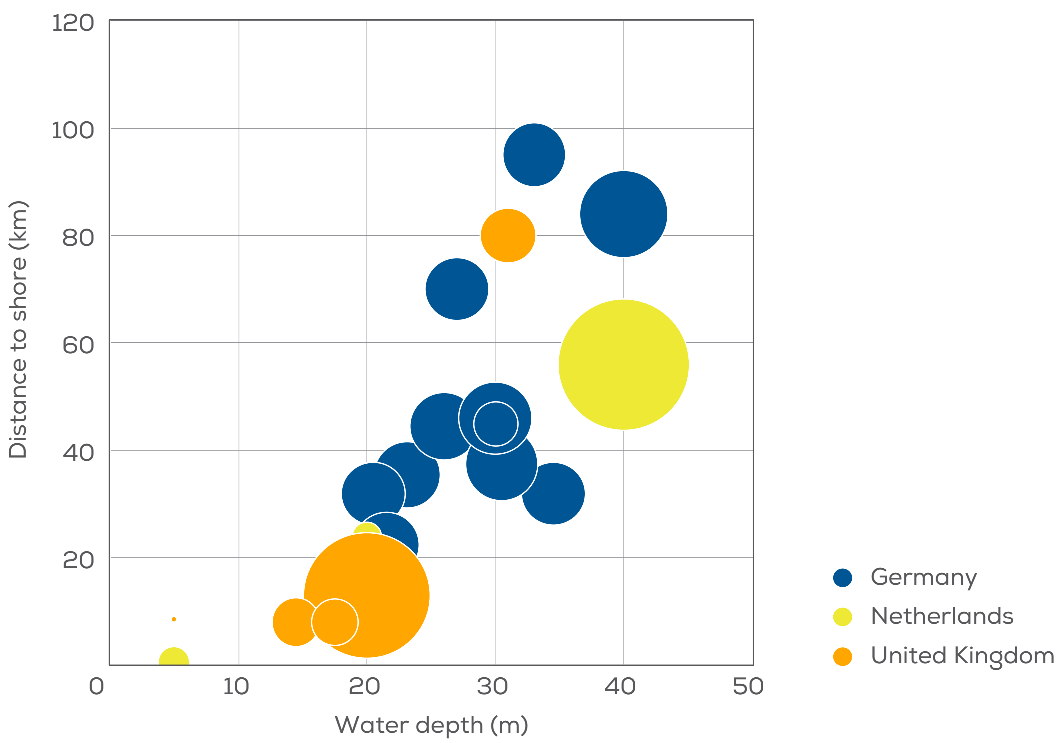
Transport and installation are two major elements of capital expenditure in offshore wind farms. Vessels, installation methods, ports infrastructure, marine infrastructure and accessibility are all areas of research that require attention. New challenges lie in the increasing size of turbines and foundations, which are already constraining or exceeding current vessels capabilities and port infrastructures.

To achieve its ambitious cost reduction targets, offshore wind needs to intensify efforts to reach an industrialised level for transport and installation systems.

New concepts need to face the challenge of installation at increasing water depths (see chart below). **Installation and access in higher sea states** will require new vessels and systems design. The innovations should allow installations under a wider weather window. In the longer term, **floating installation systems** of bottom fixed foundations need further investigation, and its cost-value should be established for a proper comparison with conventional systems.

New requirements for vessels will need development in order to handle increasingly large turbines, foundations, offshore platform and cables. R&I needs to investigate the possibility to **rethink completely traditional assembly methods for 10 MW+ turbines** for foundations, towers, nacelles and blades.

FIGURE 18
Depth, distance to shore and size of currently installed projects[25]



25. Offshore Database, WindEurope, 2016

In addition, reducing the need for very large cranes onshore and on installation vessels is important. This is equally true when addressing offshore repair and maintenance.

The installation of cables offshore represents an important source of capital expenditure. **Requirements and design for installation tools for submarine cables** need further investigation in order to achieve more efficient and cheaper processes.

The reflection on **development and validation of logistical models for planning, transportation and installation**, including analysis of weather forecasting accuracy and correlation with real metocean data, will pave the way for improvements, taking into account all the different logistical issues of the different phases, and lead to cost reductions.

In parallel, R&I will need to develop **common HSE requirements** for all installation operations, to simplify procedures, and increase the safety and pace of the installation process. Much of the offshore rule book in different areas needs to be edited as it is developed from the oil and gas offshore industry where the risk of oil and gas related explosions justified large and expensive mitigation rules.

Additional research into the calculation of noise, the cumulative effects and the subsequent enhancement of noise mitigation systems would enhance the industry's ability to reduce environmental impact. Findings should also account for the decommissioning phase.

4.2 Innovative and industrialised offshore towers and foundations, including better seabed interaction

Substructures and towers represent an important proportion of offshore wind energy costs. Therefore, innovative and industrialised towers and foundations are critical to reduce the cost of offshore wind power, similarly to the onshore wind energy industry.

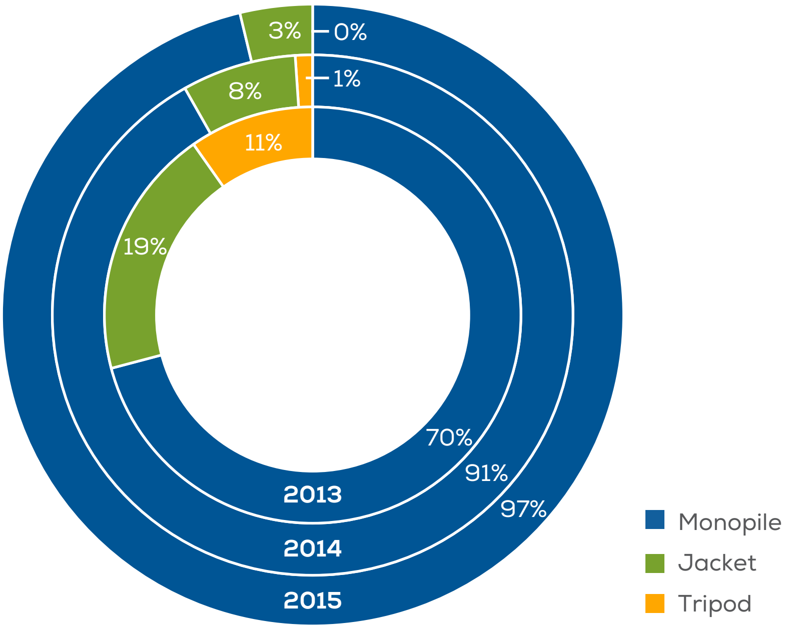
Currently, nearly all offshore turbines are built within waters depth less than 40 meters. Monopiles are the most common substructure design, and their use compared to other designs has even been increasing during the past three years (see graph below). As of 2016, the latest XXL monopiles weigh 1,300 tonnes, have a diameter of 7.8m and are over 80m in length[26]. The trend has been to continue to stretch the limits of monopile usage despite entering deeper waters. This has been done in order to maximise the use of existing assets and infrastructure. However, the use of jackets is expected to be more common in deeper waters with larger turbines. Neither tripod nor gravity base structures have been used for turbines commissioned in 2015. Other types of foundations, such as suction jackets and mono buckets[27] are now reaching a good state of maturity, and are ready for commercial deployment.

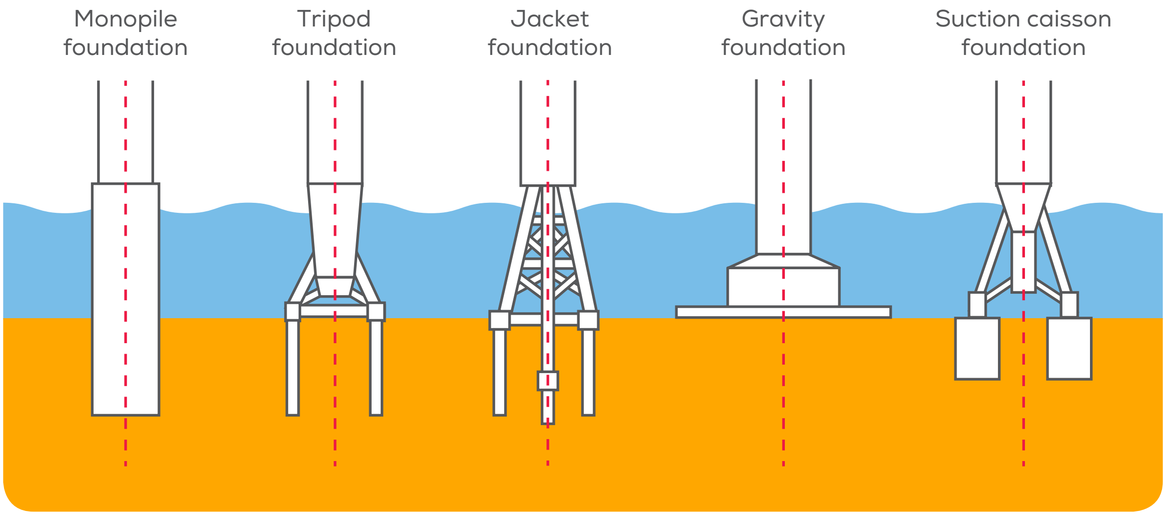
Suction caissons are best described as upturned buckets that are lowered into marine sediment, to anchor structures. This is done by pumping water out of the 'bucket' to lower the pressure inside bucket skirt, this negative pressure and weight of the foundation causes the foundation to sink into sea floor. This process is easily reversed for removal of the foundation. This type of foundation has been used in the oil and gas industry since the early 1980's to anchor floating structures to seafloor. Some installations take place at depths of over 1500 m. Two variants of suction caissons foundations are currently being developed for the offshore wind sector: the monobucket and the suction jacket foundation.

The validation of a smaller number of designs is vital to get developer buy-in and reduce project-by-project proliferation of expensive designs.

26. EEW SPC (2016) EEW SPC has produced the world's heaviest Monopile
27. universal-foundation.com

FIGURE 18
Types of foundations installed in 2013, 2014, 2015[28]





28. WindEurope offshore database, 2016

TABLE 1
Pros and cons of different types of foundation

	ADVANTAGES	DRAWBACKS
Monopile foundation	• Simple structure, relatively simple production and its shape lends itself to simple calculations • Tight packing on transport vessels • Installation without the use of heavy cranes	• Requires extra scour protection • Requires noisy pilling that has attracted installation restrictions • High hydrodynamic loads as water depth and turbine size increases • XL monopoles trigger new challenges on crane capacities due to their weight
Jacket foundation	• Very strong track record in the oil & gas industry • Handles mid-to-deep waters (30-60m) well • Relatively low weight considering its size and water depth	• Structure is more complex and time consuming to build • Higher risk of corrosion with multiple welded joints • Relatively expensive to produce • Difficult to protect against ice loads
Tripod foundation	• Provides good stability against bending moments and vertical forces	• Relatively expensive to produce • Harder to handle and instal than a monopile
Gravity foundation	• Concrete foundations are relatively cheap to build	• Size and weight (1,500 to 4,500 tonnes) of the foundation make transport and installation cumbersome • Seabed must be prepared by dredging and backfilling material
Suction caissons foudations	• Less steel required than in monopile foundations • Silent installation process • Ease of decomissioning	• More complicated structure to produce • Can only be used in certain types of seabed

The development of improved and more efficient measurement and mapping of the soil and seabed properties with various technologies (sonars, cone penetrometer tests…) would reduce the time required for conducting seabed surveys. **Improvements in the theory and methods for taking and handling of soil samples** would also be beneficial. As shallow bedrock site sampling and piling is difficult at present, the development and use of **subsea remote operated vehicles (ROVs) as a tool for rock coring** should be considered.

The **interaction between soil and foundation** needs further understanding. The PISA project[29] is an example of existing research in this field. The project is already showing good preliminary results, indicating that a reduction in material usage in monopile fabrication is possible. Additional work that builds on PISA, or extension into other foundation types would enhance this field. More specifically, the development of better **scour protection, monitoring and prevention** will minimise the risk of future problems associated with the seabed surface. Reduced buffers in design standards will enhance further cost reduction.

The fatigue properties of the tower and the substructures needs further investigation. Regarding materials, **a better understanding of the fatigue properties of corroded steel** would enhance the design life of components. The interaction of the marine environment with offshore structures, especially wave loads, should also benefit from improved calculation theory. Coatings and cathodic methods are protection techniques that will need to

29. Pile Soil Analysis project, http://www.eng.ox.ac.uk/geotech/research/PISA

Monopile foundation installation

improve in order to provide more robustness to the tower and the substructures. New forms of concrete or hybrid steel/concrete foundations could enhance the strength of substructures while decreasing their cost.

Innovative foundation concepts will need to occur in large scale facilities. This includes onshore testing for offshore foundations, especially welding and nodes, and offshore testing of novel foundations. One could also envisage multi-functional designs for issues such as desalination, fish farming, emergency military functions, environmental observation and territorial management.

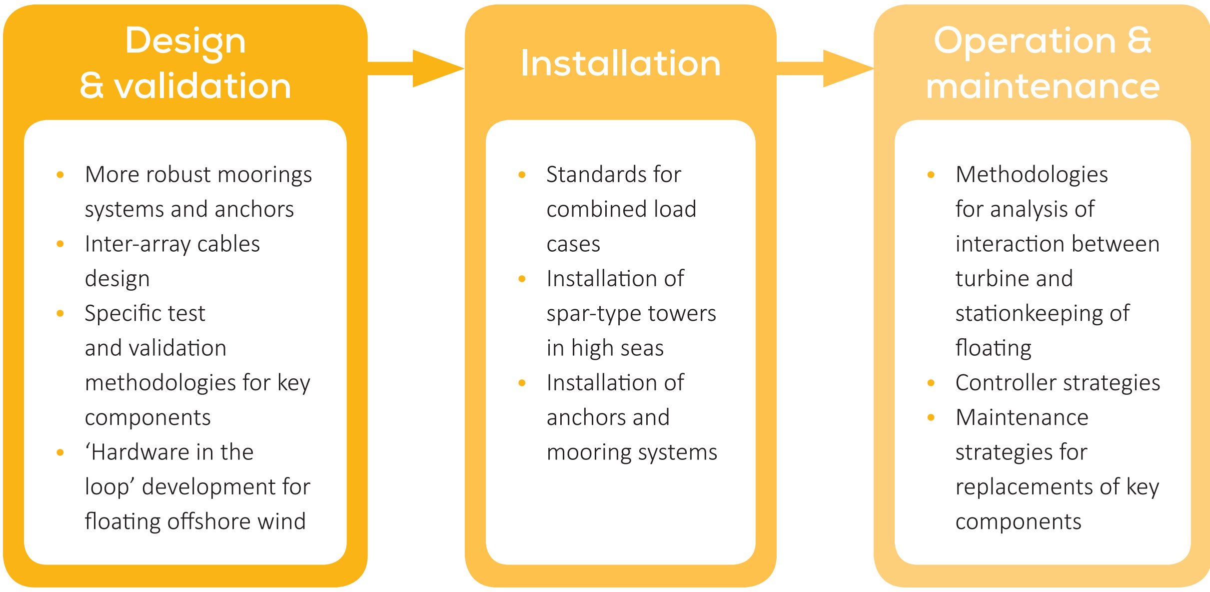
4.3 Floating offshore wind farms

Floating foundations are an alternative to fixed foundations at depths beyond 60-70 metres[30], when bottom-fixed designs are no longer viable and the offshore site is deep enough for efficient mooring. Unlocking development at these depths allows for greater potential to generate clean energy in the deeper Atlantic Ocean and Mediterranean Sea, bringing offshore wind to Southern Europe. However, the cost of floating wind power is still very high.

In 2009, a first 2.3 MW spar design floating turbine demonstration unit called Hywind was installed in the North Sea, followed by the WindFloat semi-submersible demonstrator in 2011 off the coast of Portugal. Large-scale floating wind power is still in its infancy, and R&I will enable it to reach an industrialised level in the medium to long term. The main challenges encountered in the implementation of floating offshore wind systems is to keep stability, limit displacements and maintain efficient mooring.

30. LeanWind, collaborative project, 2013

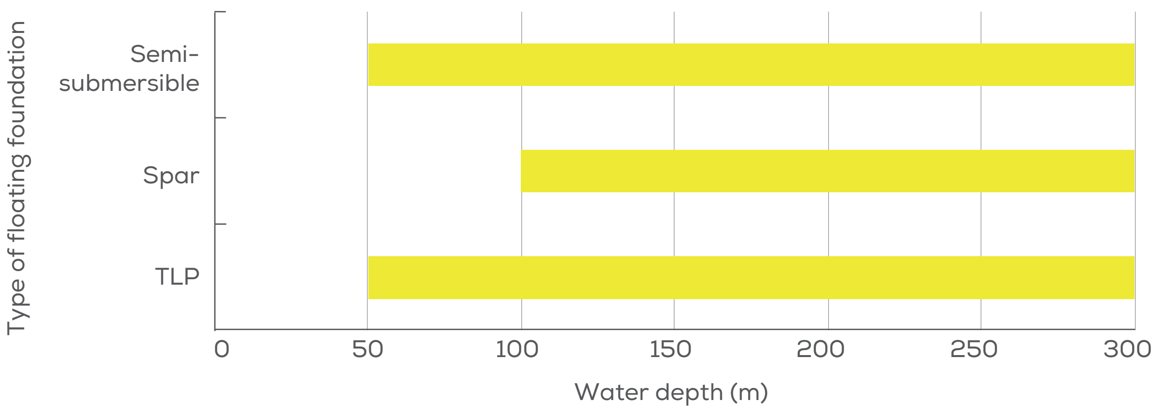
FIGURE 20
Key research topics for floating offshore wind farms



Many concepts have already been developed for floating wind. While they do not represent the whole state-of-the-art in floating wind, three types have received most attention (see figure 22) – they do not represent the whole state of the art in floating wind:

- **Semi-submersible type floating turbine:** The floating foundation comprises a few large column tubes connected to each other by tubular members, partially filled with water.
- **Spar-type floating turbine:** The floating foundation consists of a steel and/or concrete cylinder filled with a ballast of water and gravel that keeps the centre of gravity well below the centre of buoyancy ensuring the wind turbine floats and stays upright since it creates a large righting moment arm and high inertial resistance to pitch and roll motions.
- **Tension leg platform (TLP) floating turbine:** Frequently used in the oil & gas industry for water depth between 300 and 1500 meters, the foundation is moored by means of tethers or tendons at each corner of the structure.

FIGURE 21
Range of applicability for the available floating substructure technologies[31]



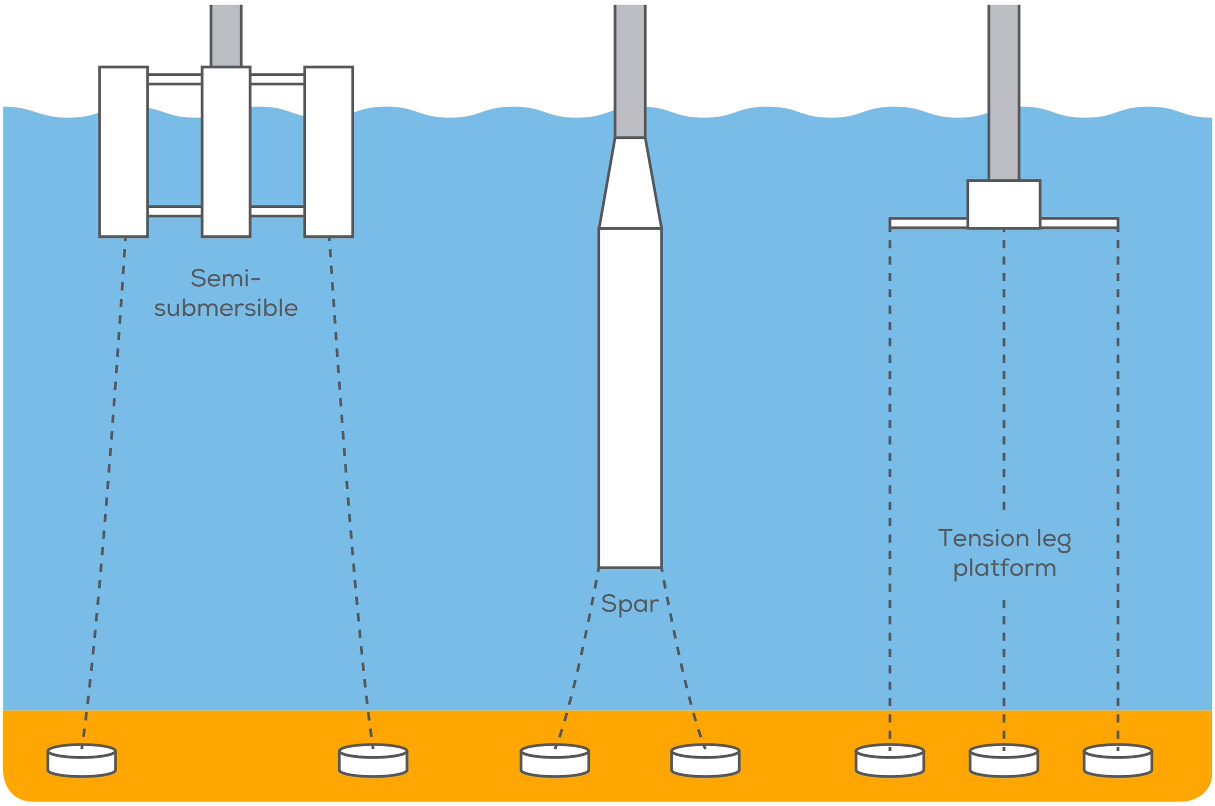
31. Design of floating wind turbine substructures, Det Norske Veritas, 2013

R&I needs to better define the ability of each technology to deal with different sizes of turbines (6 MW, 10 MW, 14 MW...). **The scaling of substructures designs and weights** should be studied and standardised for these three concepts as well as other concepts.

TABLE 2
Advantages and disadvantages of the semi-submersible, spar and TLP concepts

	ADVANTAGES	DRAWBACKS
Semi-submersible type floating turbine	• Assembly can be carried out onshore and transportation is relatively easy due to a low mass • Optimal mooring design	• Structural fatigue • Lower stability than other concepts • Active ballasting system complexity adds costs
Spar-type floating turbine	• Deep draft design reduced effects of wind, wave and currents	• Structure is large and heavy, so difficult to manoeuvre • Assembly must be done in the water
Tension leg platform (TLP) floating turbine	• Assembly can be carried out onshore and transportation is relatively easy due to a low mass • Wind has the benefitial effect of stabilising the floater pitch motion	• Lower dynamic response to waves • Construction and installation are more challenging than semi-submersible structures

FIGURE 22
The three main technologies for floating offshore wind



In terms of design, the focus should be on turbine/ foundation interaction and station keeping systems. The developments of models for **design and testing of anchors and mooring systems** will provide more robustness to floating systems. The cables will also need further investigation; R&I should develop further knowledge on **the connection of inter-array cables in floating arrays, including the lifetime and optimisation of dynamic cables.**

The development of **specific test and validation methodologies for floating wind turbines**, including key components within the turbine and balance of plant, system validation, software validation and 'hardware in the loop' (HIL) should favour an increased reliability of floating wind turbines.

Modelling the interaction between the floating turbine and its environment sufficiently accurately is important for safe and cost-effective design. Improved theoretical models for this complex interaction must be developed. Also, R&I will need to **move from single machine modelling to wind farm scale modelling** using multi-scale approach and overcome the current limitation of hydrodynamic and aerodynamic behaviour modelling using petaflop clusters.

Installation methods need to be developed. More specifically, R&I should improve the installation of anchors, moorings and substructure, horizontal tow to site and upending, and the installation methods in high sea states.

The development of **combined load cases in standards to handle floating** will be an important step for floating wind to reach an industrialised level in the installation phase.

During the operation of floating wind turbines, R&I needs to investigate methods for analysing their load and load effects. **Methodologies for analysis** need to be developed in order to pave the way for better design and operation of the offshore floating wind turbines.

The **development of controller strategies for floating systems** should trigger lower downtime and increase the life expectancy of the turbine. In parallel, the **strategies and methodologies for replaceing large components** (e.g. blades, gearboxes, generators…) on floating wind turbines will contribute to optimising the maintenance costs, and the development of such strategies and methodologies should therefore be encouraged.

Ultimately, a modular design would enable the exchange of standard elements between designs thus reducing cost and increasing reliability.

TABLE 3
Floating projects online and under development[32]

Online projects	Developer	Floating technology	Capacity (MW)	Turbine	Online	Country location
Hywind 1	Statoil	Spar	2.3	Siemens	2009	
WindFloat 1	EDPR/Repsol	Semi-submersible	2.0	Vestas	2011	
Kabashima	Toda Corporation	Spar	2.0	Hitachi	2013	
Fukushima Forward I	Marubeni Corp	Semi-submersible	2.0	Hitachi	2013	
Fukushima Forward II	Marubeni Corp	Semi-submersible	7.0	MHI	2016	

Projects under development	Developer	Floating tech-nology	Capacity (MW)	Turbine	Expected online	Country location
FloatGen	Ideol	Barge	2.0	TBA	2016	
Gicon-SOF	Gicon	TLP	2.3	TBA	2016	
Fukushima Forward III	Marubeni Corp	Spar	5.0	Hitachi	2016	
Hywind Scotland	Statoil	Spar	30.0	Siemens	2017	
InFlow	IFP EN	Semi-submersible	2.0	Nénuphar	2017	
Sea Reed	DCNS	Semi-submersible	6.0	GE-Alstom	2017	
NEDO Japan	Ideol	Barge	7.5	TBA	2017	
WindFloat Atlantic	WindPlus	Semi-submersible	25.0	Siemens	2018	
WindFloat Pacific	Deepwater Wind	Semi-submersible	24.0	Siemens	2018	
Kincardine	POR/Atkins	Semi-submersible	48.0	TBA	2018	
Dounreay Tri	Hexicon	Semi-submersible	10.0	TBAB	2018	

32. Windpowermonthly, June 2016 edition

4.4 Innovative and industrialised offshore substations and cables

As its cost is significant, electrical infrastructure offshore requires special attention. Research on offshore substations and cables can shape their future in accordance with the development of the offshore wind turbines, foundations and substructures. The related research priorities can be gathered into three main categories:

- Regulatory requirements;
- Standardisation; and
- New developments.

a. Regulatory requirements

Regulatory compliance remains a considerable proportion of the total cost of offshore wind projects. Cooperation in the development of **generic agreements and procedures for crossing oil & gas pipes, telecommunications and power cables, and clearer proximity requirements** will facilitate the deployment of large offshore cables.

In this respect, R&I can aid the development of regulation through the development and utilisation of smart mapping systems. Peripheral industries such as undersea mining will be a growing concern and wind power R&I will need to tackle the regulatory issues linked to overlapping activities with offshore wind power.

The development of grid code requirements for offshore wind farms is fundamental to ensure a proper connection to the power network. This encompasses the need to lower the area occupied by older oil & gas pipelines.

b. Standardisation

Standardisation will be key to induce cost reduction of offshore substation and cables. We have identified the following priorities for standardisation:

- Development of universal joints for subsea power cables;
- Development of standardised substation design and layout;
- Development of newer more cost effective cable types including dynamic line rating;
- Standardised methods and technologies that will enable fast and speedy repair of underwater cables when needed;
- Development of J-tube cable protection systems; and
- Development of J-tubeless cable protection systems.

c. New developments

Future developments can improve the lifetime and efficiency of the substations and cables:

- **A better understanding of fatigue in subsea array and export cables** should include efforts to better understand the **interaction between the seabed and cables** in relation to temperature dissipation or a moving seabed;
- The development of **floating substations** will open up new possibilities for offshore wind power, especially for deep water areas. The research will grow in parallel to the ones about floating foundations for turbines; and
- The development of **HVDC technologies** or suitable alternatives (including HVDC diode rectifiers, LFAC, HVAC technologies) could ensure an efficient connection of offshore wind resources to onshore loads.

5. Next generation technologies

Wind power has become a mature technology but important developments lie ahead. Dedicated scientific expertise can realise these. In the medium to long term, wind power needs a strong scientific knowledge base to develop beyond its activities of today and tomorrow. Often considered an engineering discipline, wind power also involves fundamental and pioneering research, which forms the groundwork required to create and address the long-term applications. If wind power has mainly developed through incremental research and development, it cannot ignore the opportunities that could be triggered by breakthroughs in the long run.

We have prioritised five research topics:

- Disruptive technologies;
- Next generation tests, measurements and standards;
- Smart rotor design;
- Matching site conditions; and
- Materials and structures.

Focus on achievable and real-time testing of concepts is essential to ensure that further work in these areas will deliver the desired impact in the reduction of LCOE.

5.1 Disruptive technologies

R&I needs to constantly look for new technologies and game changers for wind power. Out of the box technological advances are a chance for new breakthrough technologies and can provide interesting opportunities for the sector to soar. In the aim to achieve lower LCOE, R&I needs to look for new technologies in the rotor, in the generator and in the support structure and electrical system. R&I also needs to look at technologies from other industries that one can apply to the wind power industry and nurture nascent technologies by investigating their potential in the real world of application.

5.2 External conditions

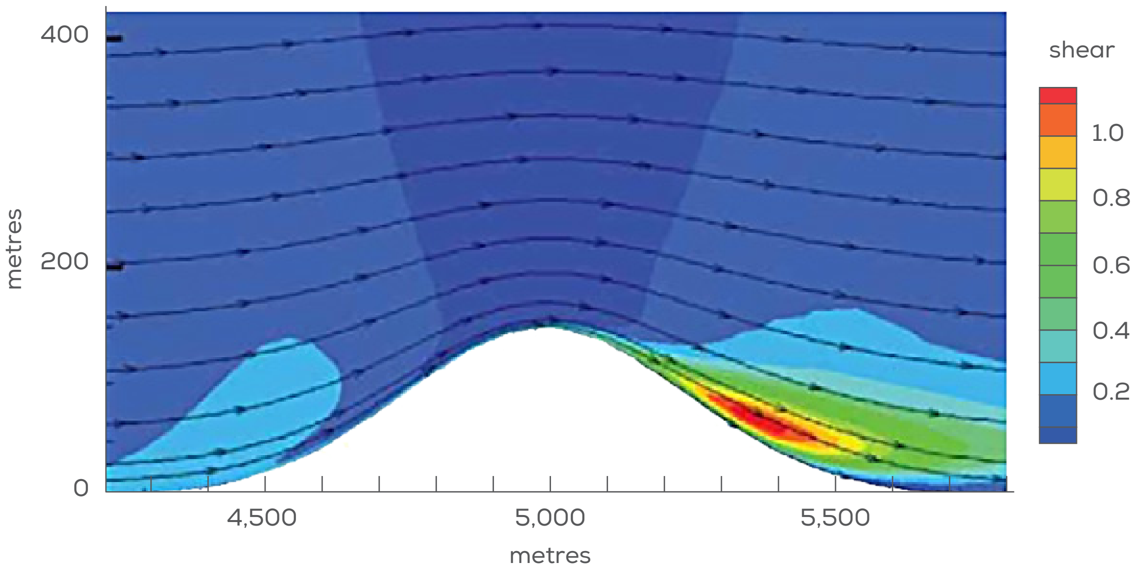
An improved understanding of external climatic conditions and their interaction with large-scale wind turbines and wind farms will provide room for further cost reduction for wind power. This includes improved quality of inflow conditions modelling as well as a better understanding of sites specificities.

Atmospheric **inflow conditions** are one important uncertainty associated with the performance of wind turbines. More specifically, **turbulence and wakes** understanding still could benefit from further research. **Complex terrains**, associated with harsh flow conditions, need further investigation to reach better wind characterisation and modelling.

A better understanding of inflow conditions would contribute a reduction of uncertainties that will lead to a more cost-effective design of turbines, and provide additional information for potential power yields. In addition, better understanding of the interaction with waves and the seabed can reduce costs for foundations

Therefore, an improved **evaluation of uncertainties** can better assess risks and possible improvements.

FIGURE 21
A complex terrain like a hill can entail significant shear downhill[33]



5.3 Rotor design

The rotor is a key target for wind technology improvement because it is the source of all the energy captured and of most of the structural loads going into the system. Research into new rotor designs will help reduce the cost of wind energy by improving the energy yields, while managing better the fatigue loads and limiting noise emissions.

Aerodynamics plays a vital role in the design process of the rotor as it determines the potential energy yield and the aerodynamic loads which influence the total cost of the turbine. The aerodynamic design of a rotor has the objective of providing the optimised geometry (diameter, number of blades, blade shape) at the lowest long-term cost of electricity. R&I needs to further investigate how to **improve aerodynamics modelling** in order to enhance better capabilities for improved rotor designs.

Aero-structure interaction can result in excessive vibrations on the blades of the turbine. This instability is caused by a strong interaction between the airflow and the mechanical structure. As the rotor size increases, the consequences of the aero-structure interaction become greater, so there is a need to investigate **accurate modelling of large and flexible blades** that would tackle this issue.

Ensuring that the rotor's noise emissions are acceptable is fundamental and must be taken into account in the design process. The **aero-acoustics** including the noise generation via turbulent fluid motion or aerodynamic forces interacting with surfaces and its propagation require further research for better designs.

Furthermore interaction of the rotor design and control strategies needs further development to optimise the balance between power performance, noise

33. Developing wind projects in complex terrains using wind software, 2012, windpowerengineering.com

emission, mechanical loading and lifetime. This includes optimisation of the 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; and the development of control algorithms to ensure the aero-elastic stability of wind turbines.

5.4 Materials and structures

The use of the materials in the turbine needs optimisation in order to improve structural integrity. Wind power R&I needs to consolidate its knowledge on currently used materials and investigate the possibility to use new types of materials.

Building efficient blade structures (lighter, stronger, stiffer, more sustainable, economical) is necessary to extend the life of the turbine and trigger cost reductions. This includes providing a basis for structural design methodologies and improving the state-of-the-art of structural design methods.

Structural reliability methods need to be developed in order to better use materials, predicting damage and cracks in an enhanced way. A sound probabilistic assessment of structural reliability will provide an optimal balance between material cost and the associated risks of failures.

New materials models and life prediction models will help further understand and anticipate the behaviour of materials in the aim to extend the lifetime of the turbine. A better understanding of the relation between processing conditions and resulting processing defects will help determine the most appropriate operation strategies for life optimisation.

5.5 Next generation tests and measurements

There is a continued need to improve the understanding of how to translate environmental conditions (e.g. wind, rain, hail, ligthning, sand, dust, waves and atmospheric salt content) into more efficient and faster, accelerated lifetime tests that demonstrate the operating life of the different components of a wind turbine in the field.

The wind energy community has already invested in fast and accurate wind measurement devices for blades, nacelles, drivetrains, support structures and other components. Yet, R&I needs to investigate **the development of novel measurement techniques and experimental tests** that will deal with an increasing complexity, notably due to the growing size of rotors. **New methodologies for the validation** of these tests can be developed, and will pave the way for more reliable and efficient wind energy production.

Enhanced test benches could test current and next generation turbines. Similar to the aircraft industry, the wind power sector needs to enhance tailor-made **wind tunnel models** in order to create better products. The aim is to provide appropriate performance items to create optimal designs for the turbine. To be useful and efficient, the test benches have to be robust and modular while carrying out their task quickly.

A wind tunnel is a tool used to study the effects of air moving past solid objects. The earliest wind tunnels were invented in the end of the 19th century, in the early days of aeronautic research to measure aerodynamic forces, pressure distribution and other aerodynamic-related characteristics. During the Second World War, the first large wind tunnels were built to test the development of supersonic aircrafts and missiles.

5.6 Wind farm control

Wind farm control can have the double benefit of increasing total wind farm performance and at the same time reducing the risk of unwanted dynamic loads and turbine interactions that can result in increased fatigue loads.

Today's control systems are generally turbine-centric, aiming at optimising the performance and, for more advanced systems, reducing the loads of individual turbines. Control is typically carried out without consideration for overall wind farm performance. It is expected that considerable benefits can be achieved through the development of control systems capable of analysing and optimising the wind plant from a system level rather than an individual turbine level. Such control systems will actively monitor the flow field, anticipate wind changes, and modify the flow through the wind farm by redirection of the turbine wakes.

In order to facilitate wind farm control measurement systems comprising sensor technologies and data analysis methodologies capable of assessing the complete flow field of the wind farm. Sensor technologies are likely to include lidars and Doppler radars. In addition, robust sensor systems for real-time monitoring of turbine loading will be required. Data analysis methodologies will most likely need to comprise big data systematics.

Control system research should aim at developing improved models and algorithms ready for use by control engineers, including a set of control methodologies applicable to a multitude of configurations that can provide guidance regarding trade-offs.

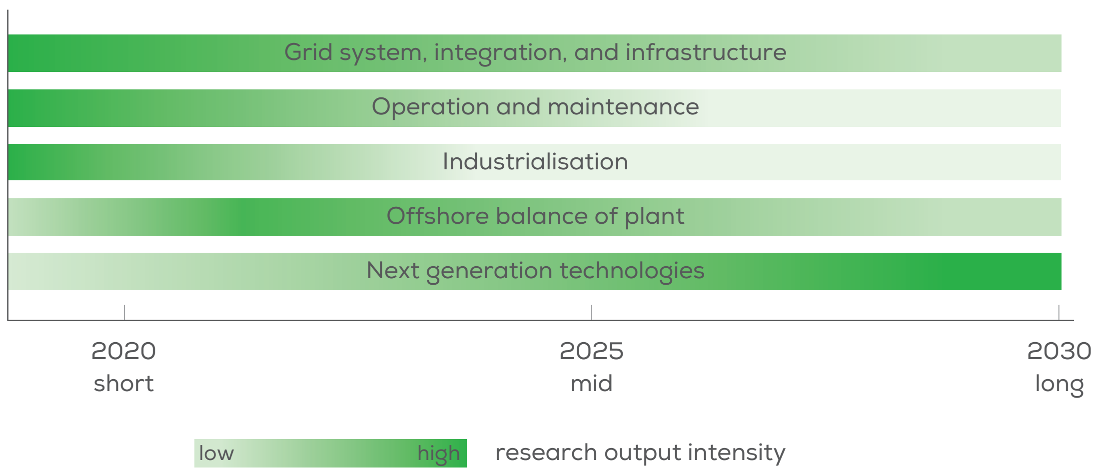
6. From R&I to deployment

Wind energy is developing at a very fast pace, with its share in the energy mix growing every day. The entire sector, from manufacturers to utilities, has proven to be flexible in a market that demands high standards in technical, environmental, social and financial aspects. However, further steps need to be taken in order to optimally integrate a large share of wind energy.

Wind R&I is one of the main contributors to the development of new solutions that will enable reaching the targets set by the European Union. Efficient market structures need to enable immediate cost reduction while maintaining high standards for the industry. As wind energy needs to grow in harmony with its surroundings, it also has to achieve full social and environmental integration.

The deployment of wind energy R&I projects will happen at different time frames and paces. The figure 24 illustrates a snapshot of the general trend of the research output intensity needed.

FIGURE 24
Research output intensity



This chapter examines five topics to enhance and sustain the deployment of wind power:

- Adapting markets and policies;
- Integrating wind into the environment;
- Ensuring public engagement and acceptance;
- Providing excellent human ressources, training and skills; and
- Financing research and innovation.

6.1 Adapting policies and markets

Policies and markets have played a major role in the deployment of wind energy. At a time when costs were high, market creating measures such as Feed-in-Tariffs started enabling massive amounts of capacity for wind. The challenges of tomorrow for the long-term success of markets and policies are now two-fold: they will have to adapt to the dramatic fall in the cost of a maturing wind technology and ensure a fair environment for all power stakeholders in a new market with significant shares of renewable energy.

Wind R&I needs to research and assess the **economic incentives and support mechanisms** for wind that will enable fast deployment at a low price:

- Support mechanisms need to be reviewed to fit the new environment (lower prices and higher penetration rates) without jeopardising investor confidence;
- Policy design specifications need to be investigated, on how they can foster favourable technology developments;
- New legal regulatory frameworks can be designed to favour further wind developments, especially with respect to offshore grids and wind farms; and
- A cost-benefit analysis should be performed on the potential effects for a higher harmonisation at European level for wind deployment.

Power markets need to adapt to the increasing shares of renewables that have a direct impact on the profile power prices which alone fail to trigger any investment signals even if additional capacity is needed (e.g. United Kingdom). New designs for power markets need to represent the new market conditions:

- Merit-Order effects on spot markets, leading to higher volatility in power prices need to be further understood, especially with very high penetration of low variable cost technologies;
- New market designs for day-ahead and intraday need to be assessed, as well as financial markets to support the integration of wind in systems with high wind shares;
- New business models for energy markets and ancillary service market; and
- Market design needs to be investigated on how to further value the increasing flexibility needs triggered by increasing shares of renewables.

6.2 Integrating wind into the environment

Compared to conventional electricity generation forms, wind energy has the highly valuable environmental advantage of not emitting carbon dioxide or other pollutants when producing power. During the past decade, the wind energy community has contributed many times to constantly increasing its environmental standards, notably through environmental impact assessment (EIA), and monitoring programmes. Yet, further research work needs to be done in order to make sure wind energy is well integrated to its natural environment:

- 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 monopoles or jackets) on marine animals;
- Cumulative effects and ecosystem level impacts of wind energy;
- Comparing and assessing methods to evaluate externalities and environmental impacts of wind energy; and
- Undertaking new Life Cycle Assessment of wind energy.

In addition to the research into integration effects, specific methods for the mitigation of known environmental effects should be developed. Such mitigation effects should include the development of bird and bat deterrent systems that effectively prevent avian animals from harmful interaction with wind turbines, such as collisions with rotating and stationary structures, and exposure to high pressure gradients at flight in and near blade tip vortices. Deterrent systems should themselves be harmless to the animals. They may include visual and auditory deterrents, preferably supplemented with observation systems facilitating the focusing of the deterrent to animals at risk.

6.3 Ensuring public engagement and acceptance

As wind energy is a clean and renewable energy source, it is traditionally linked with strong public support in a context of increasing social concerns about climate change. However the experience in the development of wind projects shows that wind farm application processes can be delayed or blocked by resistance from local communities, highlighting social acceptance as a crucial parameter for their success.

We need to tackle three dimensions in order to foster a better acceptance of wind projects:

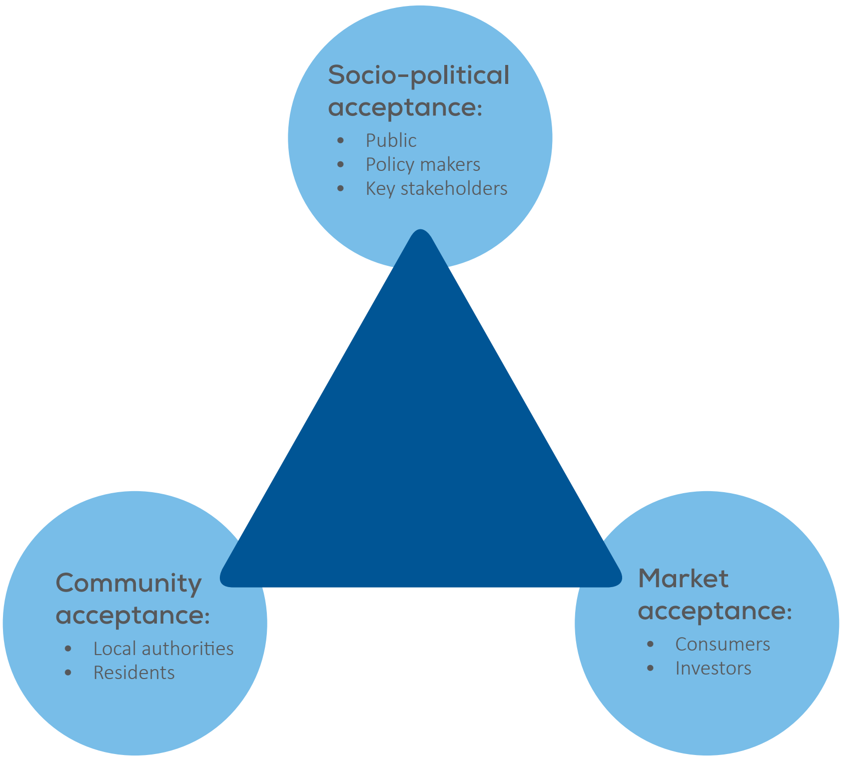
- **Socio-political acceptance** refers to the social acceptance on the broadest, most general level. This includes the acceptance of the general public but also the support of stakeholders and policy makers involved in the process of building new reweable policies;
- **Community acceptance** refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities; and
- **Market acceptance** refers to the process by which market parties adopt and support the energy transition. This includes green power marketing and willingness to pay for green power.

Relevant research priorities are:

- Identify and prioritise the major public engagement issues for onshore and offshore wind farms (with sensitivities between the national, regional, and local level);
- Assess how to best improve public engagement regarding onshore and offshore wind power using effective participatory approaches;
- Decrease noise emissions of wind turbines during the installation and operation phases;
- Investigate and communicating benefits and costs of wind energy to build a more robust public knowledge base of benefits and costs of wind energy; and
- Investigate customer choice and green power marketing (including green pricing programmes).

FIGURE 25

The triangle model of social acceptance[34]



34. Social acceptance of wind energy projects, IEA Wind, 2007

6.4 Human deployment

The wind industry today employs 1.1 million people worldwide including 330,000 people in Europe. As installed capacity is set to grow, we can expect this figure to rise in the coming years, highlighting the need of the industry for first-class skilled and trained people. In 2013, the wind industry estimated a shortage of 7,000 qualified personnels, a figure that could increase to 15,000 by 2030[35].

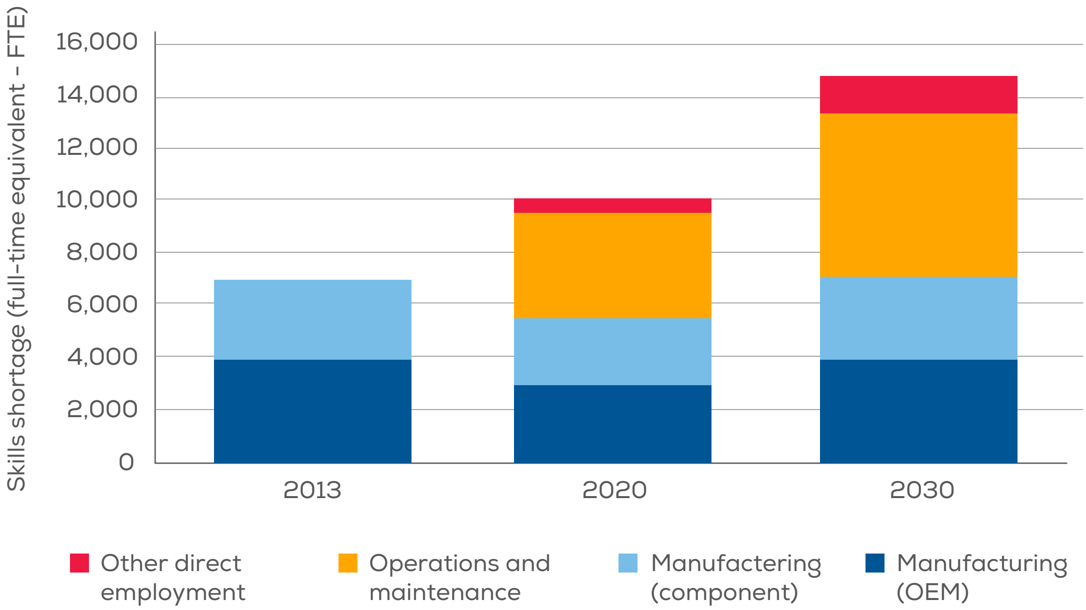
There will be new needs for human resource development within the wind energy sector. As the total installed capacity grows, the skills shortage in the operation and maintenance sub-sector will increase sharply (see graph below), and become the greatest source of new wind energy jobs by 2030. The growing needs in offshore wind and repowering also require attention. In terms of skills, there is an economy-wide concern about the low number of graduates from schools and universities opting for STEM (science, technology, engineering and mathematics) courses.

Introducing industry experience in training and education is key to shaping future academic curricula. Universities and industry stakeholders could jointly fund internships or create industrial scholarships.

Relevant research priorities are:

- Elaborate solutions for skill and resource drain towards high salary sectors like the oil & gas, such as compensation schemes based on career development;
- Assess the need for O&M, repowering and offshore education quantitatively and qualitatively; and
- Review current wind energy masters programmes, encourage the creation of new programmes and create European level programmes such as the European wind energy master[37].

FIGURE 26
Skills gap 2013-2030[36]



35. Renewable Energy and jobs, Annual review 2016, IRENA
36. Workers wanted: The EU wind energy sector skills gap, EWEA, 2013
37. Ewem.tudelft.nl

FIGURE 27
Skills areas within the wind industry

Academic research, design and R&D

- Loads and aerodynamics
- Consultancy
- Electrical/grid (inc. software)
- Wind turbine technology

Finance

- Wind energy finance
- Project finance
- Corporate finance

Project engineering (construction and O&M)

- Electrical/power engineering
- Civil engineering
- Mechanical engineering
- Commissioning
- Maintenance

Manufacturing engineering

- Electrical/power engineering
- Quality control
- Diagnosis
- Metal fabrication
- Machining
- Mechanical and electrical fitting
- Testing

Project management, project development and multidisciplinary skills

- Project management
- Energy resources assessment
- Spatial planning/consenting
- Policy.regulatoryanalysis
- Project development and project management
- Legal experts
- Communications

VET (Vocational education and training)

- Service and maintenance
- Installation and commisioning
- Introduction to wind energy
- On-site safety (eg. Global Wind Organisation training platform)
- Fire fighting
- Tower climbing
- Rescue
- First-aid

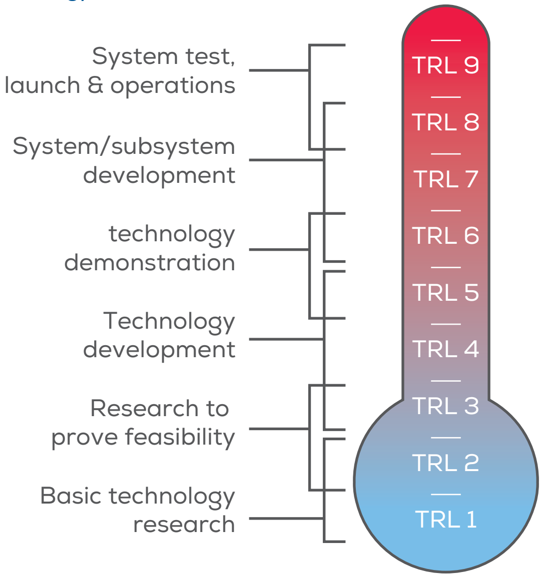
Business development

- Direct sales
- Marketing
- Communications

6.5 Financing research and innovation

The European Commission's Energy Union strategy, adopted in 2015, dedicates one of its five dimensions to R&I. The European Strategic Energy Technology plan (SET-Plan) will play a fundamental role in a new European research and innovation strategy designed to accelerate the transformation of the energy system.

FIGURE 28
Technology readiness levels



In its aim to stimulate the development and deployment of non-nuclear low carbon technologies, the SET-Plan seeks to improve new technologies and bring down costs by contributing towards the financing of projects at all technology readiness levels.

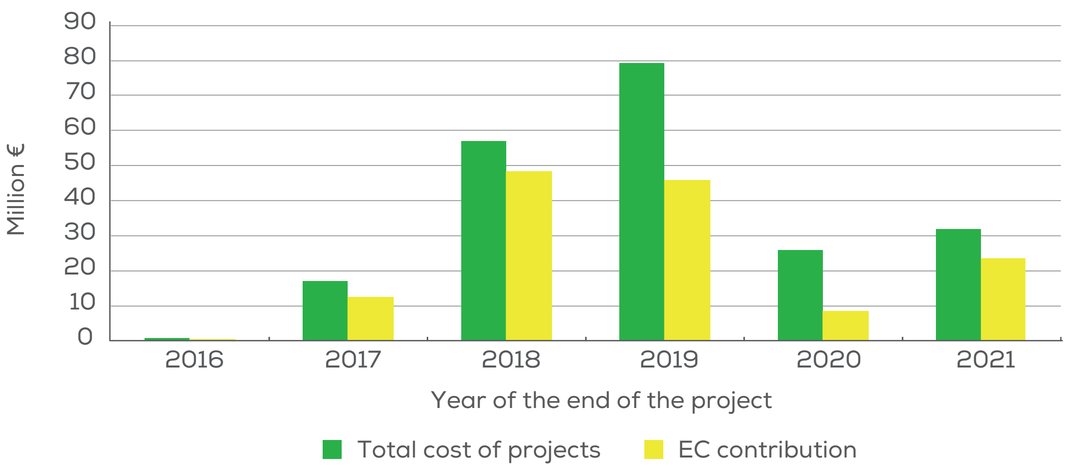
Wind energy is a key element to the implementation of the SET-plan and whilst the industry has a positive track-record in bringing down costs it still needs an annual investment of €600 million to realise its objectives. This budget should come from private investors, and from both EU and national programmes. Support is needed at both EU and national level to enable early deployment of innovative technologies and encourage economies of scale.

a. Horizon 2020

Horizon 2020 is the biggest EU research and innovation programme with nearly €80 billion of funding available over seven years (2014 to 2020) in addition to the private investment that this money will attract. It promises more discoveries and breakthroughs by taking great ideas from the lab to the market.

The programme includes a significant budget for energy, with €5.9 billion[38] currently allocated to non-nuclear energy research for the period 2014-2020. Among this research, wind energy has received almost €150 million for projects ending between 2016 and 2021. The available budget of the H2020 Energy Challenge in the Strategic Work Programme 2018-2020 represents approximately €2.38 billion.

FIGURE 29
Horizon 2020 – currently signed wind energy specific projects[39]



38. https://ec.europa.eu/programmes/horizon2020/en/h2020-section/secure-clean-and-efficient-energy
39. CORDIS data base, 2016, WindEurope Elaboration

b. Innovation Fund - NER400

NER300 is the EU's funding programme for innovative demonstration projects for renewable energy and carbon capture and storage until 2021. It has awarded €2.1 billion to 38 innovative renewable energy projects as well as one CCS project.

The European Commission proposed the NER400 Innovation Fund for the period 2021-2030. It will build on the NER300 programme but will additionally include measures to decarbonise industrial production.

c. European Regional Development Fund

The European Regional Development Fund (ERDF) aims to reduce economic and social disparity between the EU's regions. One of the ERDF's four priority areas for 2014-2020 is 'the low carbon economy'. A minimum percentage of ERDF funding must be channeled towards 'low carbon projects' in regions. Specifically:

- 20% for more developed regions;
- 15% for transition regions; and
- 12% for less developed regions.

d. Connecting Europe Facility

The Connecting Europe Facility (CEF) is the EU's €33 billion plan for boosting energy, transport, and digital infrastructure between 2014 and 2020. Under the CEF, €5.85 billion is available for trans-European energy infrastructure projects such as gas pipelines, transmission grids, LNG terminals, gas storage, and smart grids. The European Commission has drawn up a list of 248 EU projects of common interest (PCIs) which may apply for CEF funding.

e. European Investment Bank finance for wind

Development banks play a crucial role in financing innovative onshore and offshore projects where costs and risk factors are high and private banks may be reluctant to intervene.

Energy projects benefitted from more than €50 billion in loans from the EIB between 2011 and 2015 with approximately €8 billion allocated to wind power projects[40]. 34 projects were specifically dedicated to offshore wind and 32 were dedicated to onshore wind.

The EIB will have a crucial role to play in order to finance innovative large-scale projects offshore and the repowering process onshore.

InnovFin is an example of EIB initiative that covers a wide range of loans and guarantees which can be tailored to innovators' needs. By 2020, InnovFin is expected to make over €24 billion of debt and equity financing available to innovative companies to support €48 billion of final R&I investments.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40. Figures elaborated from the European Investment Bank Data Base

f. R&I funding at EU member state level

The EU member states gross domestic expenditure on R&D as a percentage of GDP has grown from 1.8% in 2007 to 2% in 2014. However, the EU remains at a distance from its Europe 2020 target of 3 %.

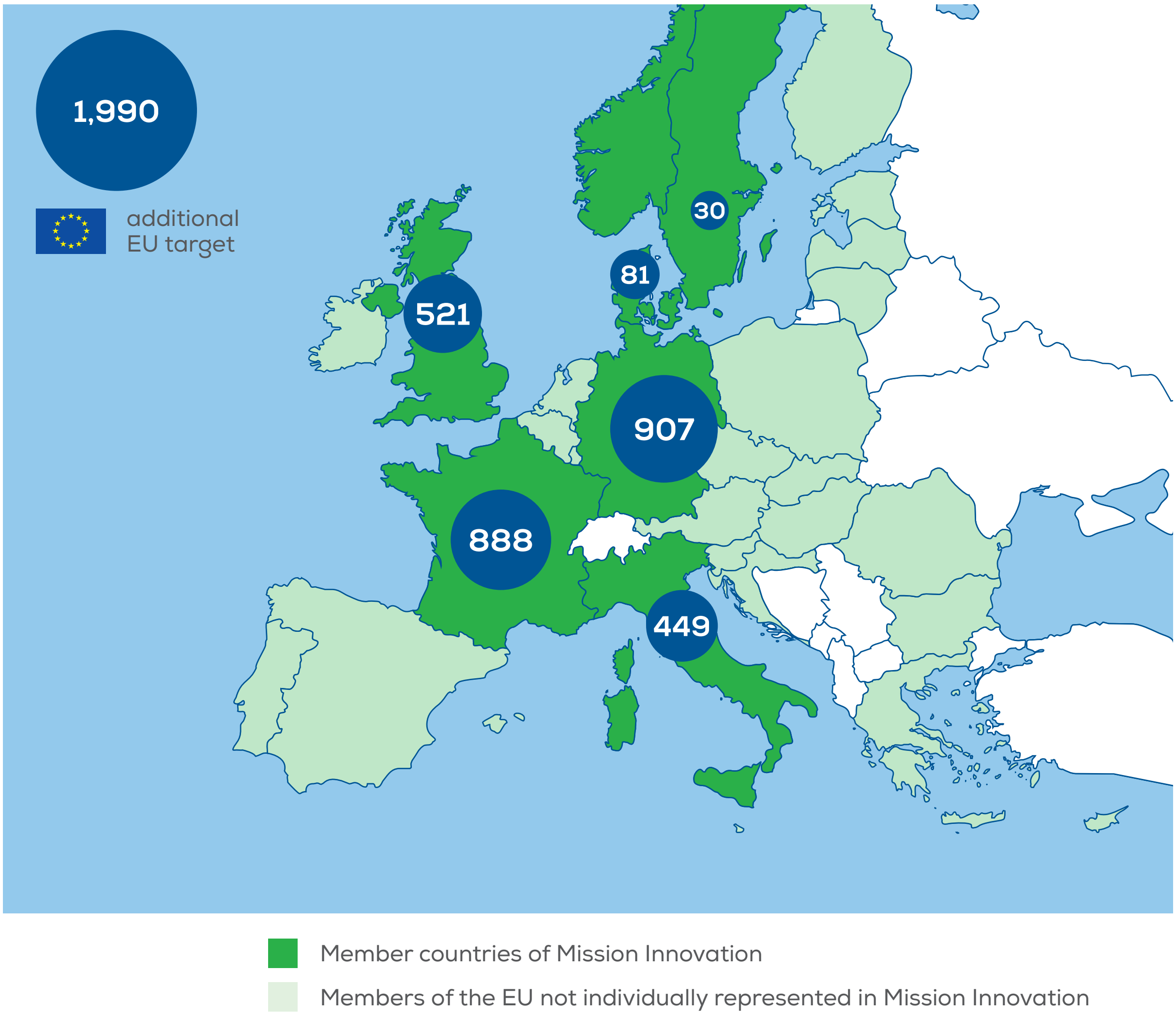
Post COP21 discussions exemplified in the initiative Mission Innovation show a shared desire from EU member states to accelerate global clean energy innovation in order to support economic growth, energy security, and a global response to climate change.

The figure below shows some EU member states ambitions in clean energy R&D[41].

Funding on R&I for renewables is available at private, national and transnational level. Coordinated action between all levels will maximise output.

FIGURE 30

Five-year target amount (million € per year) directed to clean energy innovation stated in the Mission Innovation initiative



41. Stated in Mission Innovation, a post COP21 global initiative that accelerates public and private clean energy innovation.

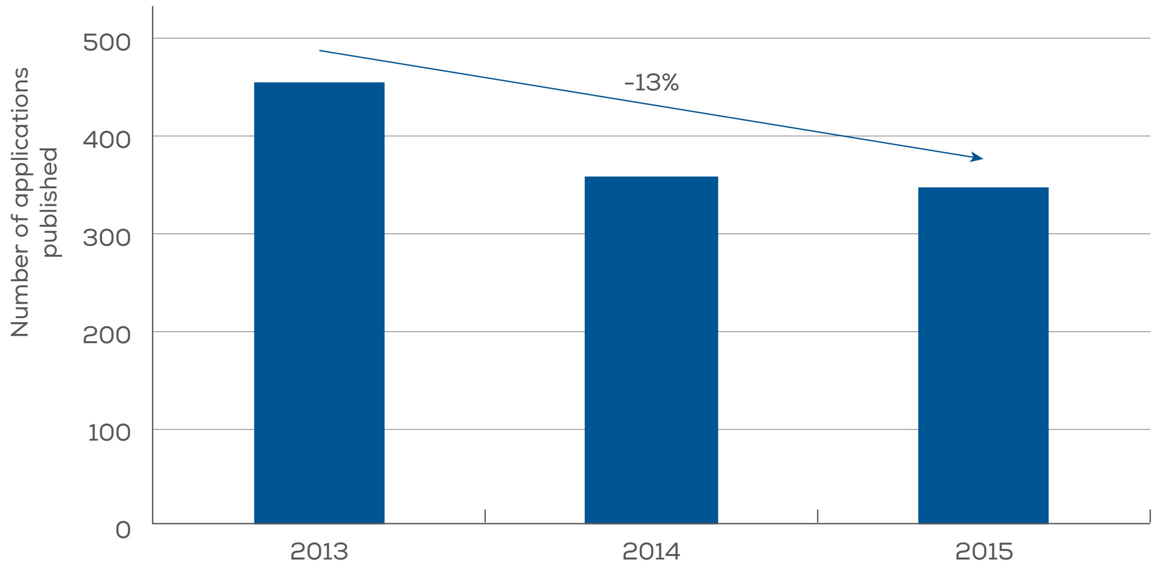
g. Private investment in R&I

European wind turbine manufacturers have traditionally invested massively in R&I (around 7% of annual turnover in 2011[42]) to stay ahead of the competition.

However, decreasing policy ambition and/or abrupt changes to regulatory regimes in many EU markets had a negative impact on private R&D funding[43] from turbine manufacturers, which is today comparable to that of the leading Chinese wind turbine manufacturer (around 2.5% of annual turnover[44]). A 13% decrease in patent applications from European companies between 2013 and 2015 also signals that the EU technology leadership in innovative wind turbine technologies may be at risk in the coming decades.

An enhanced public-private dialogue is therefore necessary to maintain the region as a pioneer in groundbreaking wind technologies in the face of tougher international competition.

FIGURE 31
TOP 5 OEMs cumulative patent application in the European Patent (EP) database[45]



42. MAKE, December 2015
43. MAKE, December 2015
44. MAKE, December 2015 - based on a comparison between three leading European manufacturers R&D spending and their Chinese counterpart
45. MAKE, December 2015

h. Optimisation of processes towards public funding

To fulfil the key R&I targets set by the wind energy community, the process for accessing EU funding needs to be optimised in order to make it more attractive for stakeholders to engage in funded projects. This will be instrumental in reaching the ambitious SET-Plan targets and to maintain global leadership in the sector.

ETIPWind therefore recommends:

- Designing calls for projects with a clear project scope, rationale and focused objectives;
- maintaining focus on key value parameters (LCOE, integration, etc.) when drafting calls and assessing proposals;
- considering a “challenge approach” by setting ambitious objectives with proposals to achieve them;
- making project calls for two or more parallel projects with similar scopes;
- shortening the duration of (at least certain types of) call processes for example via the introduction of a fast track procedure;
- considering innovative, nimble project processes where in-process adjustments are allowed;
- assessing proposals on execution and implementation capabilities;
- requesting large consortia only where clearly justified by nature of project scope, e.g. standardisation, and to accept small consortia for innovation-focused projects;
- structuring calls to reflect respect of intellectual property and confidentiality; and
- reducing bureaucracy drawing from the experience of efficient national schemes, e.g. Carbon Trust.

7. ETIPWind structure and members

The scope of ETIPWind is to create a virtual and physical platform via which the wind energy community can communicate, coordinate and collaborate its work and activities related to research, innovation and technology. The ambition is to define and agree on concrete R&I priorities and communicate these to the European institutions and other decision making bodies in order to support the ambition of reaching the RES targets for 2030.

Thus, the purpose of the activities carried out is to enable ETIPWind to perform its advisory activities to policy makers in a systematic and coordinated way, which facilitates collaboration transparency and information sharing with all stakeholders of the wind energy community and policy makers.

ETIPWind is an independent entity that conducts its activities in a transparent manner. The proposed structure outlined thereafter provides a more direct link between policy makers and top-representatives of industry from across the value chain, while at the same time it ensures due representation of the research and academia communities in the decision-making structure.

ETIPWind works according to the following structure:

- ETIPWind Steering Committee
- ETIPWind Advisory Group
- ETIPWind Secretariat

7.1 ETIPWind Steering Committee

The ETIPWind Steering Committee takes all key decisions. It consists of representatives from the wind energy industry (16 seats) and wind energy research community (8 seats), and meets every three months. It identifies both short and long term R&I topics where collaboration and public funding has the highest impact.

TABLE 4
ETIPWind Steering Committee

Organisation	Name
ABB	Adrian Timbus
CENER	Antonio Ugarte
DNV GL	Lars Landberg
Dong Energy Wind Power	Jørn Scharling Holm
DTU	Peter Hauge Madsen
DTU	Hans Ejsing Jørgensen
DTU	Klaus Skytte
ECN	Peter Eecen
E.ON Climate & Renewables	Ralph Chamberlain
EDF Energies Nouvelles	Stéphanie Muller
EDP Renewables	Rui José Castro Chousal
ENEL Green Power	Federico Fioretti
Fraunhofer IWES	Kurt Rohrig
Fraunhofer IWES	Arno Van Wingerde
Iberdrola Renovables Energía	César Yanes Baonza
LM Wind Power	John Korsgaard
MHI Vestas Offshore Wind	Anders Bach Andersen
Renewable Energy Systems Ltd	Mike Anderson
Senvion	Martin Knops
Siemens Wind Power	Aidan Cronin
Sintef	John O. Tande
Statoil	Rune Yttervik
Vattenfall	Bo Svoldgaard
Vestas	Agnar Gudmundsson

7.2 ETIPWind Advisory Group

The ETIPWind Advisory Group consists of Chief Technology Officers (or equivalent) of the leading companies in the wind energy industry. These experts represent the entire value chain and come from manufacturers, developers and utilities.

The Advisory Group steers the strategical objectives on R&I, answering the European Commission request to have an industry-led reflection on the Strategic Research and Innovation Agenda 2016.

TABLE 5
ETIPWind Advisory Group

Organisation	Name
ABB	Ernst Scholtz
Acciona	Miguel Nunes Polo
Dong Energy Wind Power	Christina Aabo
E.ON Climate & Renewables	Jorgen Bodin
EDF Energies Nouvelles	Pierre-Guy Therond
EDP Renewables	Jorge Casillas
ENEL Green Power	Fabrizio Bizzarri
Enercon	Nicole Fritsch-Nehring
Iberdrola Renovables Energía	Cristina Heredero
LM Wind Power	Roel Schurring
MHI Vestas Offshore Wind	Torben Hvid Larsen
Nordex	Jorge Scholle
Renewable Energy Systems Ltd	Mike Anderson
Sentient Science	Ward Thomas
Senvion	Bernhard Telgmann
Siemens Wind Power	Ruediger Knauf
Statoil	Rajnish Sharma
Vattenfall	Ole Bigum Nielsen
Vestas	Anders Vedel

7.3 ETIPWind Secretariat

WindEurope acts as the secretariat for ETIPWind. The secretariat communicates and coordinates between the ETIPWind Steering Committee, ETIPWind Advisory Group and the relevant Directorates General of the European Commission and national decision makers.

TABLE 6
ETIPWind Secretariat

Organisation	Title	Name
WindEurope	Projet manager and content coordinator	Edit Nielsen
WindEurope	R&I analyst and technical content developer	Aloys Nghiem

ETIPWind®, the European Technology and Innovation Platform on Wind Energy, connects Europe's wind energy community. Key stakeholders involved in the platform include the wind energy industry, political stakeholders and research institutions.

The scope of ETIPWind is to create a virtual and physical platform via which the wind energy community can communicate, coordinate and collaborate its work and activities related to research, innovation and technology. The ambition is to define and agree on concrete research and innovation (R&I) priorities and communicate these to the European institutions and other decision making bodies in order to support the ambition of reaching the RES targets for 2020 and beyond.

Thus, the purpose of the activities carried out is to enable ETIPWind to perform its advisory activities to policy makers in a systematic and coordinated way, which facilitates collaboration transparency and share information with all stakeholders of the wind energy community and policy-makers.

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ISBN 978-2-930670-10-2

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