STRATEGIC RESEARCH AND INNOVATION AGENDA

2018

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

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

CONTENTS

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1

FOREWORD

Historically, the wind energy sector has been one of the champions of applied technology Research & Innovation in Europe. This has made wind power competitive with traditional fossil power generation. Onshore wind is now the cheapest form of new installed power capacity. Wind power and solar PV are no longer a niche market, but still need support and a stable market outlook to fully mature. At the same time, the entire power system is set to undergo dramatic changes.

In order to mitigate the adverse effects of carbon and other emissions on our climate, the whole energy system has to decarbonise rapidly. To do so, variable renewables will need to grow exponentially. Electrification of energy intensive industries and the transport sector will be key. Heating and cooling will also need to electrify, as more sustained extreme weather conditions, caused by climate change, will significantly increase demand.

Climate change will also alter the way we think about energy consumption, distribution and generation as a whole. Acute environmental challenges are already driving China to experiment with integrating renewables in a new transformational grid at a speed that is difficult to comprehend in Europe. Their goal is to develop more responsive, flexible, adaptive and intelligent power delivery systems. The speed with which Asian governments are changing gears poses a direct challenge to EU global leadership in renewables. EU policies must keep Europe ahead of the curve in green power technology.

There has never been a stronger need for a forward-looking EU industrial Research & Innovation policy than today. With traditional industrial sectors in decline, Europe has to double down on its efforts to support clean and renewable industries that develop innovative solutions that ensure a prosperous and sustainable society going forward. Yet many national plans do not articulate the acute need for a rapid transition to a clean, sustainable and electrified society and low carbon pricing still provides a free ticket to pollute. Business as usual and incremental changes will see Europe lagging behind the green energy revolution and missing the Paris Agreement and Energy Union targets.

This updated Strategic Research and Innovation Agenda outlines the major areas where Research & Innovation support offers best value for money. Research & Innovation funding support is critical in driving down the time to market of new fundamental innovations, in training new generations of scientists and engineers, and in producing applied research necessary for the short-term gains that European companies need to remain competitive in the global market.

The updated Strategic Research and Innovation Agenda contains 5 pillars of Research & Innovation and highlights the need for increased work on technologies that facilitate the integration of renewables in the grid, increase the reliability and quality of power production and reduce the costs of wind energy.

I would like to thank the members of the ETIPWind Steering Committee for their continuous efforts in defining a common vision for the wind energy sector and crafting both the 2016 and 2018 Strategic Research and Innovation Agenda. I also want to thank the Advisory Group for their invaluable insights and strategic guidance throughout this process.

I would also like to thank the European Commission for their support in breaking the boundaries around wind energy. In addition, I would like to send my warm regards to our colleagues from the ETIP SNET, ECPE and the ECSEL joint undertaking for the constructive dialogues on common Research & Innovation priorities.

Lastly, I would like to thank WindEurope CEO Giles Dickson and his staff, including ETIPWind Coordinator Alexander Vandenberghe, for their continued support to this platform, giving the sector a more cohesive interface with EU and national policy makers.

2

WIND ENERGY AT THE HEART OF THE ENERGY TRANSITION

THE EU AS A GLOBAL LEADER IN RENEWABLE ENERGY TECHNOLOGY

The EU is committed to becoming the global leader in renewable energy technology and moving away from a fossil fuel based energy system. The EU Energy Roadmap 2050 aims to ensure a clean, competitive and reliable energy supply for all European citizens and businesses. The Roadmap underscored that decarbonising the EU economy by 80 to 95% requires a complete decarbonisation of the power system. A strong acceleration of the electrification of heating and cooling, transport and industrial processes is needed and must be driven by renewables.

This energy transition represents a remarkable opportunity for Europe which is well placed to become the Global Clean Energy Investment hub. In 2017, global clean energy investment totalled $333.5 billion.[1] Leading the way on wind energy Research & Innovation and on system integration of renewables will allow Europe to maximise the economic benefits from the global energy transition by unlocking investment in high-end technology and leveraging Europe's ingenuity and knowhow. This is especially true for the wind energy sector where Europe already has established a strategic advantage.

WIND ENERGY: A STRATEGIC INDUSTRY FOR EUROPE

Wind energy has the potential to be at the core of the new European power system. Wind energy capacity in the EU could double by 2030 from 160 GW to 323 GW, meeting close to 30% of the EU's power demand. Apart from the societal benefits and supplying consumers with safe, clean and emission free energy at affordable costs, this growth could also unlock some 569,000 jobs in Europe and contribute €90bn to the EU's GDP.[2] To realise this potential the EU will need to strengthen its commitment to wind power.

Wind energy has achieved dramatic cost reductions thanks to major public and private investments in R&I. In just four years the strike prices for onshore wind auctions have dropped from over 100 €/MWh in 2013 to around and even below the 40 €/MWh mark in 2017. And costs in offshore wind are falling rapidly too. In 2014 bids were coming in at over 150 €/MWh, whereas in 2017 prices dropped to 65 €/MWh and even lower.[3]

The energy transition will challenge the EU to lead in developing solutions for an upgraded market design. This includes work on the provision of ancillary services by variable renewables and it will require addressing the challenges related to seasonal storage. This is needed to ensure Europe fully harnesses the potential of variable renewable energy solutions when addressing various energy system needs.

WHY RESEARCH AND INNOVATION MATTERS

The EU is able to compete in mature industries such as aviation and automotive because of its sustained efforts to support Research & Innovation. If the EU is to deliver on its commitment to be a global leader in renewables, the same logic should apply to wind energy technology. Europe needs to support this strategic sector by sustaining the current cost reduction trend, both in onshore and offshore wind, while at the same time ramping up the transition towards a flexible energy system with variable renewables at its core. Delivery on this will pose formidable Research & Innovation challenges.

The European wind energy sector invests over 1 billion Euro, nearly 5% of its direct contribution to GDP,[4] annually in de-

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1. Bloomberg New Energy Finance, *State of clean energy investment*, 2017
2. WindEurope, *Local Impact Global Leadership*, 2017
3. WindEurope analysis of of historic data on auctions and tenders, see annex 6.1.
4. WindEurope, *Local Impact Global Leadership*, 2017

> **EU support in the form of project grants and other financial instruments such as equity and mezzanine finance will remain instrumental in keeping the industry-wide cost reduction trend going.**

velopment of new cutting-edge technologies to drive down costs even further and facilitate the integration of wind energy into the energy system. The industry is investing heavily in digitalisation. Digital technologies are a key enabler and will be vital to secure the European wind energy sector's global leadership. Still, public support is central to retaining global leadership in the wider energy transition and to keep EU companies competitive in the global market. The share of EU content in global installed capacity has been dropping since 2011 and any further decline puts existing jobs (262,000 in 2016) and the positive trade balance that wind energy creates for the EU (€2.4 bn in 2016) at risk. A stronger EU wind energy industry could double its employment level in the EU and contribute twice as much to the EU's GDP by 2030.[5]

EU support in the form of project grants and other financial instruments such as equity and mezzanine finance will remain instrumental in keeping the industry-wide cost reduction trend going. Achieving competitiveness vis-à-vis conventional energy still requires major technological breakthroughs. EU programmes such as Horizon 2020, InnovFin and NER300 have greatly helped the sector to move forward. We urge the European Commission to earmark support for the wind sector in the upcoming programmes Horizon Europe and the ETS Innovation Fund, as more progress is still to be made.

For instance, delivering zero subsidy bids for offshore wind in Germany and the Netherlands will require a big leap in turbine technology with the development of bigger (13-15 MW) wind turbines, together with new technological developments and innovative techniques across the entire supply chain to manufacture, install, operate, maintain and decommission them. Targeted support at national and European level is needed to ensure the right infrastructure is available and a stable supply chain develops to allow the wind energy sector to take this next crucial step.

MAXIMISING THE IMPACT OF PUBLIC FUNDS IN A RESOURCE SCARCE ENVIRONMENT

Across Europe, national budgets are under severe pressure. Public spending on Research & Innovation is dwindling or stabilising as governments have to answer for every Euro spent. In such a resource scarce environment, it is critical that public support for Research & Innovation focusses on those technologies that will have a lasting positive impact on society. For the energy sector this means investing in those technologies that drive the wider energy transition and deliver tangible results in the short, medium and long term. The wind energy industry has firmly established itself as a strategic sector for the EU and is a safe bet for major investments. The sector has continuously outperformed initial expectations and will play a leading role in the European energy system.

This Strategic Research & Innovation Agenda (SRIA) provides policymakers at EU and national level with a consolidated, forward looking and tangible set of priorities from the entire sector that will be instrumental in delivering on the EU's ambitious energy and climate objectives. In particular, it aims to voice the wind energy sector's contribution to Horizon Europe and the ETS Innovation Fund and to articulate the sector's commitment to the implementation of the SET Plan. The wind energy sector is committed to a holistic pan-European approach to Research & Innovation and urges national governments to align their policies with the wider European needs of the sector articulated in this SRIA.

Recommendations for Horizon Europe

- Earmark 5 % of the Horizon Europe budget on Climate, Energy and Mobility for wind energy Research & Innovation;
- Support technologies that establish a flexible energy system with wind energy at the core;
- Continue incremental investments in established technologies such as onshore wind;
- Invest in new technologies to support the leap towards bigger and more efficient wind turbines;
- Invest in enabling technologies to electrify heating & cooling, industrial processes and transport;
- Facilitate market-uptake of floating offshore wind concepts through regulatory improvements.

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[5] WindEurope, *Local Impact Global Leadership*, 2017

3

IMPACT OF THE 2016 STRATEGIC RESEARCH & INNOVATION AGENDA

3.1 HORIZON 2020

Horizon 2020 (H2020) is the EU's main funding instrument for supporting Research & Innovation. It has a budget of some 77 billion euro, spread over 7 years (2014-2020). The details of the programme are outlined in multi-annual work programmes that are updated every two years. The work programmes contain 17 thematic sections spread over three main Pillars: *Excellent Science, Industrial leadership and Societal Challenges.* Each thematic section stands on its own and includes the overall objectives, the respective calls for proposals, and the topics within each call. These topics are the concrete Research & Innovation challenges that the European Commission wants to address and for which it provides public support on a project basis. Most of the support for wind energy Research & Innovation can be found in the thematic section "Secure, clean and efficient energy" under the pillar *Societal Challenges.*

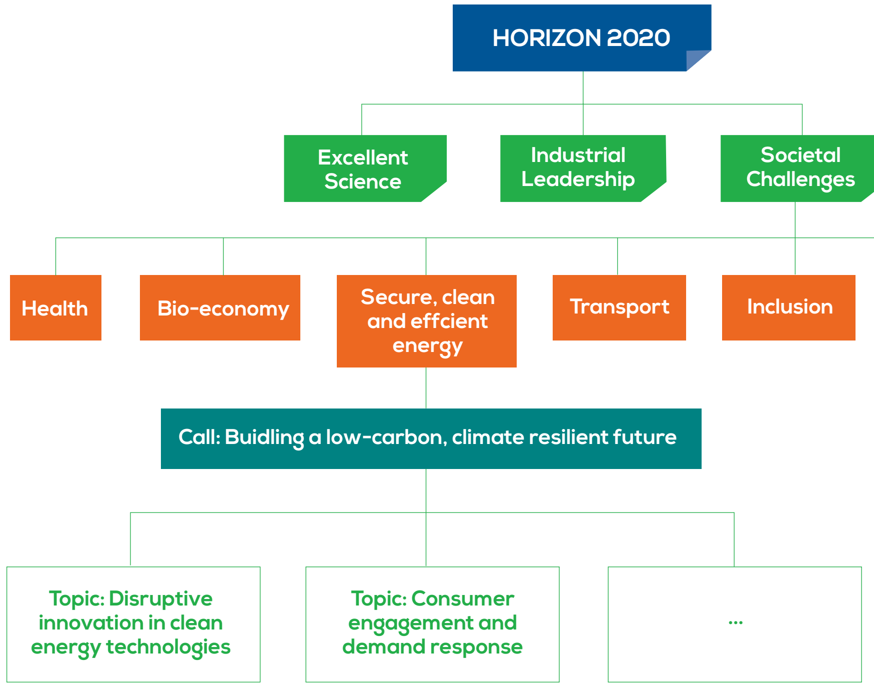

Figure 1 Schematic breakdown of the place of wind energy related Research & Innovation topics within the H2020 work programme for 2018-2020.

The 2016 ETIPWind Strategic Research & Innovation Agenda (SRIA) has made a valuable contribution to the drafting of the 2018-2020 work programme on "Secure, clean and efficient energy" of H2020. At first glance, the work programme seems to underfund the wind energy sector. Traditionally, most support for the wind energy sector was earmarked under calls related to renewable energy technology. Based on the theoretical budget of the heading "Global leadership in renewables" in the 2018-2020 work programme, other technologies such as solar photovoltaics, geothermal energy and biofuels are poised to benefit more from EU support. However this analysis does not tell the whole story for two reasons.

Firstly, the European Commission has decided to reduce the number of technology specific topics in the 2018-2020 work programme. The aim of this more technology neutral approach is to ensure better value for money, as the best projects will compete to secure the necessary funding. It means that high quality wind energy projects could secure funding that has not been earmarked beforehand. The total amount of technology neutral funding under "Global leadership in renewables" is around 73 million Euro (figure 2, see "RES General").

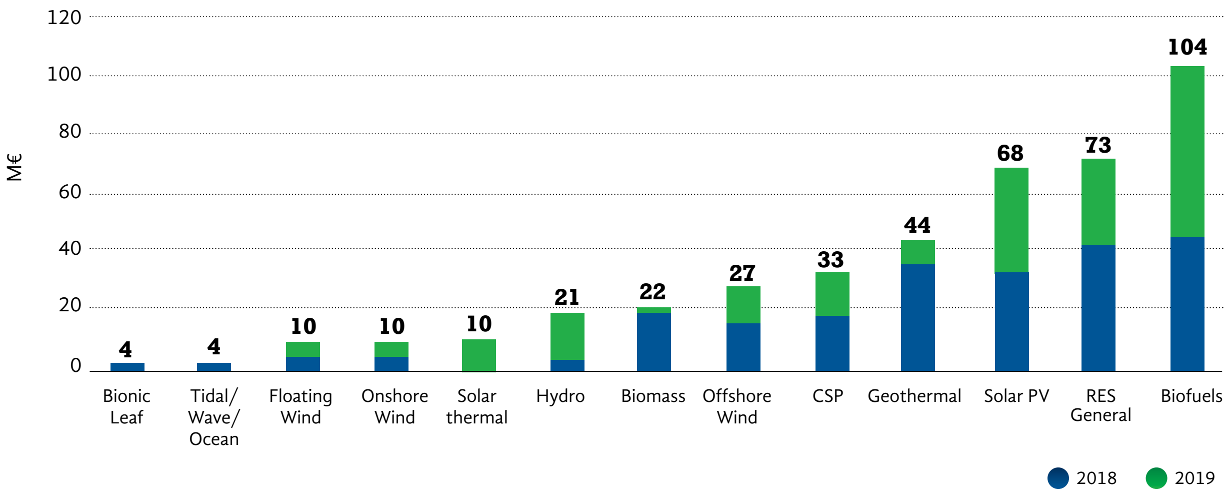

Figure 2 Theoretical EU budget in support of Research & Innovation in renewable energy technologies under the heading"Global leadership in renewables" in the H2020 work programme 2018-2020 (in million euro).

Secondly, the wind energy sector is maturing at a fast pace. This also impacts the sector's needs. System integration, digitalisation and new materials have all become increasingly important. This entails that support for research priorities of the sector can be found under other calls in the work programme.

To fully understand the extent to which the 2018-2020 work programme on "Clean, secure and efficient energy" is aligned with the priorities laid out in the 2016 Strategic Research & Innovation Agenda (SRIA), we have analysed all the topics in the work programme. We have identified all those that reflect the priorities from the 2016 SRIA and grouped them according to the 5 pillars of the SRIA. From this analysis we can see clearly that all the priorities are in fact covered by the 2018-2020 work programme, albeit unevenly (Figure 3). A more detailed breakdown of this analysis can be found in Annex 6.2.

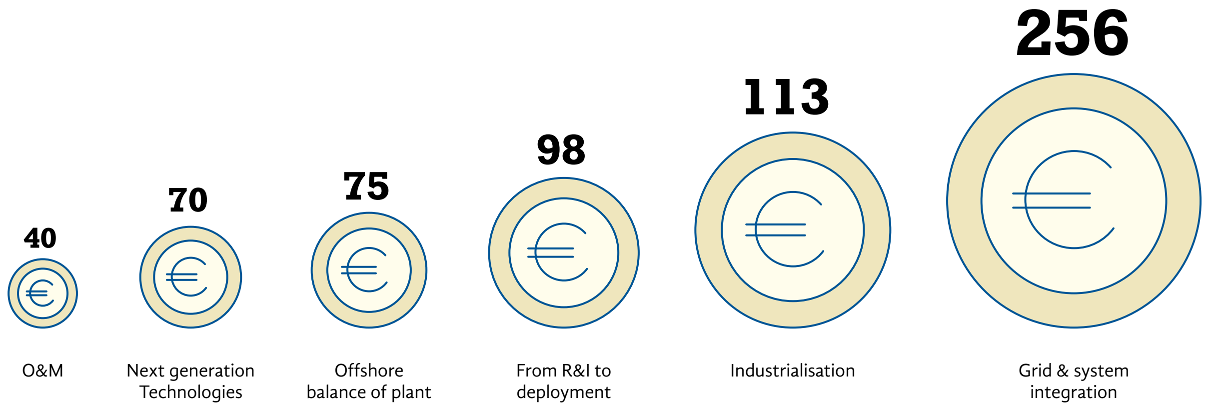

Figure 3 Maximum EU funding allocation in H2020, work programme 2018-2020 supporting Research & Innovation activities linked to the priorities of the 2016 SRIA (in million EUR).

3.2 IMPLEMENTATION OF THE INTEGRATED SET PLAN

The Strategic Energy Technology (SET) Plan has been the Research & Innovation pillar of the EU's energy and climate policy since it was adopted in 2008. 7 years later, in 2015, it was updated and rebranded the Integrated SET Plan to better reflect the ambitions of the Energy Union towards a decarbonised energy system. The Integrated SET plan voices the EU's ambition to become the number 1 in renewables and focuses on those low-carbon technologies that have the highest innovation potential for delivering quick cost reductions and improved performance.

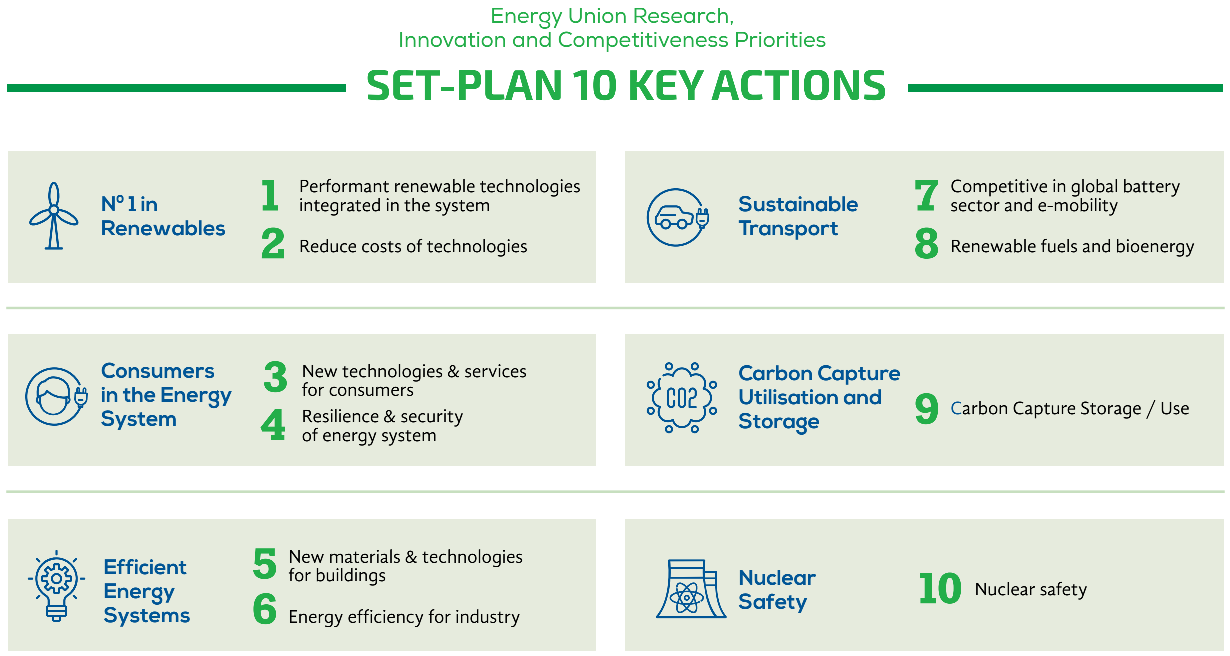

Figure 4 The 10 key actions of the Integrated SET Plan

With regard to global leadership in renewables, the Integrated SET Plan identifies 5 key technologies: offshore wind energy, solar photovoltaics, concentrated solar power, ocean energy and geothermal energy. The plan outlines two strategic targets for offshore wind energy.

1) Reduce the levelised cost of energy (LCoE)[6] at final investment decision (FID) for fixed offshore wind by improvement of the performances of the entire value chain striving towards zero subsidy cost level for Europe in the long term.
2) Develop cost competitive integrated wind energy systems including substructures which can be used in deeper waters (>50m) at a maximum distance of 50 km from shore with a LCoE[7] of
    a. less than 12 ct€/kWh by 2025 and to
    b. less than 9 ct€/kWh by 2030, striving towards cost competitiveness.

A temporary working group, bringing together national governments and sectoral stakeholders, was tasked to develop an Implementation Plans to reach these targets. Aidan Cronin, chair of the ETIPWind Steering Committee, acted as co-chair for the temporary working group and the ETIPWind secretariat was heavily involved in the drafting process. The final version of the Offshore Wind Implementation Plan was approved on 13 June 2018. The document explicitly recognises the influence of ETIPWind and echoes the priorities of the 2016 Strategic Research & Innovation Agenda (SRIA).

The implementation plan contains 9 priority actions and 6 of them are directly linked to the 2016 SRIA. Of the three remaining priority actions, two tackle non-technical barriers and bottlenecks and one focuses on industry's commitment to developing new 10-15 MW wind turbines. For each action several subactions with concrete targets and deliverables are defined. All the subactions will contribute to the strategic targets for offshore wind. More than 15 key actions areas of the 2016 SRIA can be directly linked to one or more subactions of the offshore wind implementation plan. This demonstrates the value of the SRIA in helping policymakers at EU and national level to develop Research & Innovation funding policies.

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[6] The costs for delivering the electricity to onshore substations are taken into account within the LCoE.
[7] Ibid.

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RESEARCH & INNOVATION PRIORITIES

This Strategic Research and Innovation Agenda outlines those research priorities where crossborder and crosssectoral collaboration is needed and should be fostered by public support. For this reason turbine technology is generally omitted in the documents. This does not mean that there is no need for further Research & Innovation in this field. Rather, it is a sign that the industry will carry out that research using its own resources to gain a competitive edge in the global and domestic markets.

There are 5 Research & Innovation priorities. In order of strategic importance they are: grid & system integration, operation & maintenance, next generation technologies, offshore balance of plant and floating wind. There are three changes compared to the 2016 SRIA. Firstly, industrialisation has become a transversal topic and is no longer a stand-alone pillar as standardisation and upscaling manufacturing processes will be needed across the entire supply chain. In total, the SRIA identifies 4 transversal, crosscutting themes supporting developments in wind energy Research & Innovation. Secondly, due to its enormous potential, the maturity of the sector and the specific Research & Innovation needs, floating wind is now a separate pillar. Thirdly, priorities are set between the pillars.

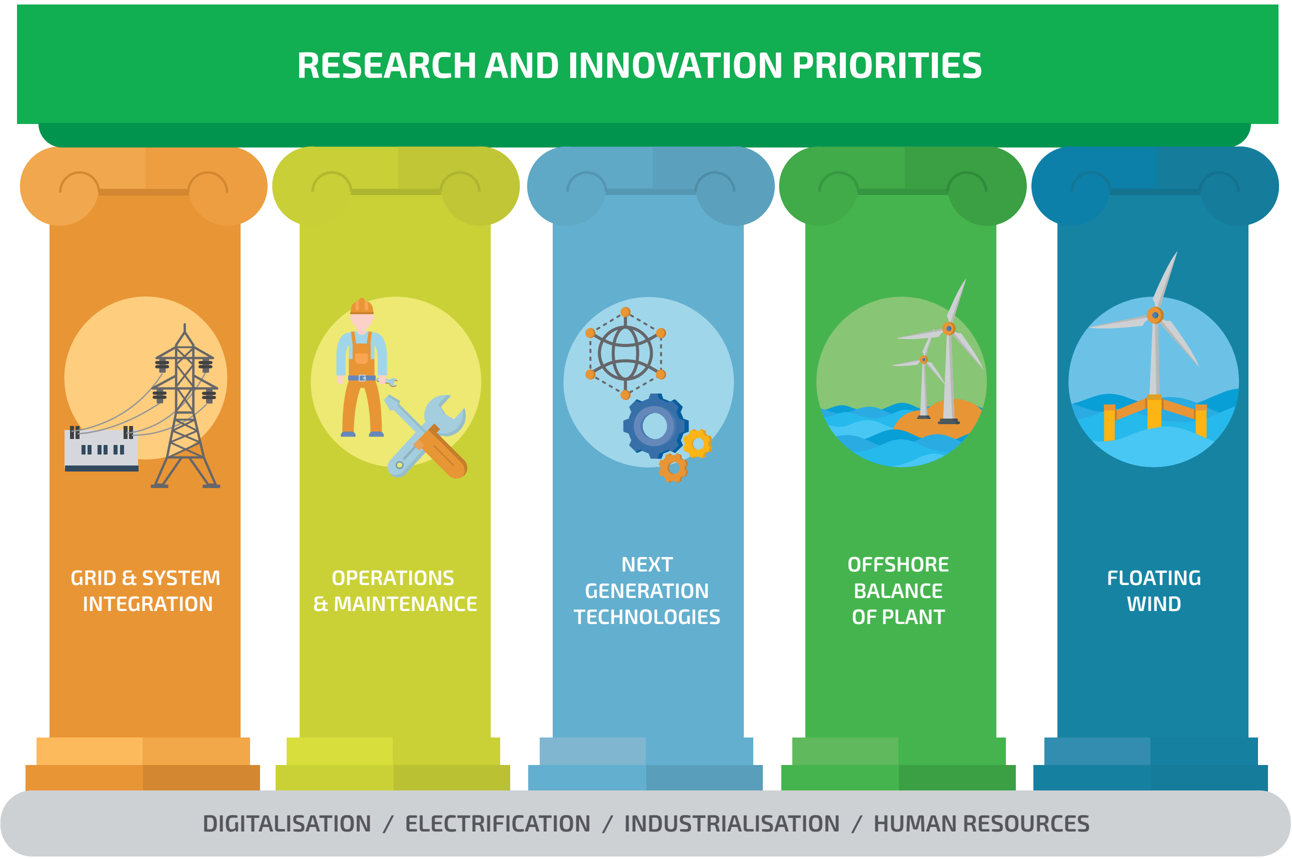

Figure 5 The 5 pillars of wind energy Research & Innovation.

4.1 TRANSVERSAL TOPICS

Technology developments in wind energy have turned the sector from a niche market to a strategic industrial sector accounting for 36 billion Euro of the EU's GDP in just a few decades.[8] The growth of the European wind energy sector means it is becoming an integral part of the European industrial fabric. In this light, the wind energy sector is also increasingly affected by larger economic trends and challenges, such as globalisation, digitalisation and the effects of climate change.

The sector's exposure to current global economic trends today also has an impact on the Research & Innovation priorities. In this section we wil identify four cross-cutting trends that underpin the sector's strategic priorities: digitalisation, industrialisation, electrification and human capital. The wind energy sector will need to innovate so it can turn the disruptive potential of these four trends into a benefit. The trends also indicate the increasingly systemic research needs of the wind industry. Whereas the sector is now capable of supporting most developments in its core technology with its own resources, it will need public support to address systemic challenges, such as electrification and digitalisation.

At the same time, the wind industry needs to broaden its horizons in order to achieve maturity. It needs to unlock new technological possibilities and team up with other industries. Valuable lessons in the field of industrialisation and standardisation can be learned from other advanced manufacturing industries. Sector coupling with energy intensive industries will be key to facilitate the integration of wind power in the energy system.

Digitalisation

Variable renewable energy and distributed generation will be crucial building blocks of the future energy system. The sheer amount of data collected, created, stored and communicated to surrounding systems will become almost equal in importance with the energy produced. Today, wind turbine manufacturers and operators are compiling vast amounts of data that could be mined, but most of the generated data is never seen, let alone analysed or optimised. Many operators simply do not have the resources or experience needed to develop and adopt more sophisticated data analysis tools and digital solutions. For real-time monitoring, engineers select a few indicators, other indicators are checked at semi-regular intervals. Most of the collected data will never be consulted unless a failure occurs.

Yet as the economics of wind energy face continued pressures, digital applications could unlock significant value for industry participants across the entire supply chain. Over the next decade, between 40 and 80 GW of wind energy will reach the end of its designed operational life. Some of these assets will be fit to continue safe operation beyond this time. Digital solutions will play an increasing role in assessing an asset's condition and remaining lifetime, as well as optimising lifetime management strategies for wind turbines. Creating digital twins for prognosis of failures in key components helps operators to decide for how long they can sweat the asset (i.e. operate it without maintenance interventions) and decide at what point maintenance, overhaul or replacement of components will be most cost-effective.

> **Over the next decade, between 40 and 80 GW of wind energy will reach the end of its designed operational life.**

Bilateral data-sharing agreements with research institutes could help to unlock new discoveries through enhanced data analysis. For EU supported projects, data will be shared on the principle "as open as possible, as closed as necessary". Further development of ShareWind, the metadata catalogue developed by the EERA Joint Programme on Wind Energy will help to make data findable, without making sensitive data publicly available.

Finally, a largely untapped potential for digitalisation lies in creating high quality data exchanges between wind operators and the surrounding energy ecosystem. Sharing operational data, for instance with system operators, could unlock new horizons of productivity and increase the integration of wind power in the energy mix. This integrated data architecture will allow the wind energy industry to fully realise its enormous potential.

Industrialisation

Industrialisation is one of the key enablers to reduce the cost of wind power. Knowledge gathered through repetition and procedures reduce the technical risks of manufacturing and project execution, and reduce the time to market of new innovations. It is a natural step the wind sector has to take in order to achieve economies of scale and improve cooperation along its entire value chain. While many wind turbine components are standardised, a large number still needs the level of standardisation seen in other heavy equipment markets, where standard high quality components are used across the industry. In addition, enhanced automation and advanced robotics will increase the production rate and robustness of components.

The need for industrialisation is highly visible in the manufacturing and installing of large components, cold climate solutions, grid connections & communications and floating offshore wind technology, and requires standardised tests and validation methods for product design and quality assurance. Unfortunately, many projects in the wind energy sector are still developed as one-off turnkey custom projects, rather than as a chain of projects with similar base requirements and limited front-end customisation. Establishing for instance an industry standard for testing grid compliance prior to instal-

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[8] This number includes both the direct and the indirect contribution of the sector (WindEurope, *Local Impact Global Leadership*, 2017).

lation will significantly reduce the time to operation of new wind power plants.

To encourage industrialisation and standardisation, the wind energy sector will work closely with public authorities to promote public funding for projects that will:

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

Electrification

Fighting climate change, air pollution and delivering on the Paris Agreement commitments requires replacing fossil fuels by renewables within the power sector and beyond. In today's EU energy mix electricity accounts for 22%, transport for 32% and heating and cooling 46% of energy demand. As large amounts of competitive renewable electricity are available today, a rapid electrification of the most carbon intensive energy uses is the best and most efficient way to decarbonise and grow Europe's economy. By 2030, renewables could represent over 50% of electricity demand and wind power could be the biggest contributor[9].

Electrification of new demand application can bring flexibility beyond the power system. Electrification can help to integrate larger shares of variable generation by better matching demand with the available supply, and reduce the dependence on carbon-intensive back-up generation. In parallel, incentives for demand response, storage and smart grids will be needed to address inflexible loads.

Electrifying Europe's industry and heating sector is a priority. These two sectors have the most important potential of fossil fuel displacement because they make up most of the EU's final energy demand and GHG emissions. It will also strengthen Europe's energy security and economy as 54% of its energy demand was imported in 2015 for a total cost of €261 billion according to the European Commission[10]. Electrification can take off quickly at a relatively low-cost as the required technologies are already widely available. The transport sector is also set for large scale electrification due to the falling costs of electric vehicles.

Considering different technology paths to maintain Europe's industrial leadership in wind energy is key. Sector coupling with electric vehicles and industrial heat-pumps is ready for commercialisation in the short-term and will have a substantial impact. Besides electrification, solutions exist to transport electric energy to other carriers. Links with other sectors such as Power-to-Gas or -Hydrogen will probably take off after 2030, even though developments on the hydrogen market could trigger new business cases for wind power plant operators. In all, developing alternative technologies for a variety of processes will ensure the EU keeps up with decarbonising its industry and maintains its global leadership in low-carbon technologies.

Human Resources

The wind power sector must further assess and specify its need for qualified human resources in terms of engineers, scientists, experts and promoters. It needs to expand to all sector activities and technologies. Support for temporal mobility among relevant personnel, both technicians and managers, from industry and research entities will ensure a continuous renewal of qualified human resources. One sector that requires more attention in the coming years is the services sector. As wind energy assets with an installed capacity of 40 to 80 GW will come to the end of their designed lifetime, there are important economic advantages to be made in either optimising operations and maintenance, extending assets' lifetime or the repowering of entire wind power plants. All of which will require the availability of more skilled labor.

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[9] WindEurope, *Wind Energy in Europe: scenarios for 2030*, 2017

[10] Directorate-General for Energy (European Commission), *EU energy in figures*, 2017

4.2 THE FIVE PILLARS

GRID & SYSTEM INTEGRATION

As wind energy becomes a mainstream source of power generation, wind turbine technology and grid infrastructure must develop accordingly. Research & Innovation has to contribute to a better understanding of and interaction between wind power plants and the power system, as well as to the development of stronger grids that are more capable of handling higher amounts of variable renewable energy. In addition, there are a number of regulatory and market design issues that are equally important to transform the power system and are in need of upgrading. This includes the operating principles that rule the transmission system operators. These principles are currently outdated and are generally unfavourable to wind energy.

Integration of wind energy is also dependent on enhanced digitalisation of power markets. Smart metering, billing and trading will unlock new business opportunities and demand-side solutions providing flexibility, and allow consumers to proactively choose for green renewable energy.

As the electrification of transport, heating and industrial processes increases, developing strategies to optimise electricity generation and demand are gaining in importance. Power to gas applications and solutions that couple wind power plants directly with energy intensive industries should be addressed on a long term basis.

Key action areas

1. Energy system flexibility solutions, including ancillary services;
2. Strategic grid expansion planning and operation;
   Improved storage solutions, particularly seasonal storage;
3. Development of hybrid systems.

Energy system flexibility solutions

The development of enhanced virtual power plant and substation concepts will help to provide a wider view of wind power plant management and its possible contribution to system balancing. We expect the development of more accurate and longer term forecasts for variable energy resources and new sources of demand (electro-mobility, hydrogen production, etc.) to facilitate the aggregation of generation and demand, which will ease the integration of wind power in the energy system.

As a mainstream source of electricity, wind power plants need to provide grid services like conventional sources whenever feasible. The capabilities for ancillary services from individual turbines and wind power plants are well proven today, especially for frequency and voltage support services. However, more work is needed on mitigation tools for harmonics from power electronics (converters), as well as on the ability for wind power plants to act as standalone generation units (islanding, grid forming). In addition to these technical capabilities, research should also address solutions for market design implementation. These include the design of suitable market products providing flexibility and the design of platform communication systems. In particular we identify following topics:

> **The development of enhanced virtual power plant and substation concepts will help to provide a wider view of wind power plant management and its possible contribution to system balancing.**

- Development of new data driven controls for ancillary services;
- Assessment of the impact of grid support (i.e. curtailments) on asset lifetime;
- System stability analysis (e.g. system modelling, harmonics, power quality improvement);
- Inertia requirements in systems with high penetration of variable renewables;
- Tools that foster collaboration between TSOs, DSOs and aggregators (generation & demand).

Strategic grid expansion planning and operation

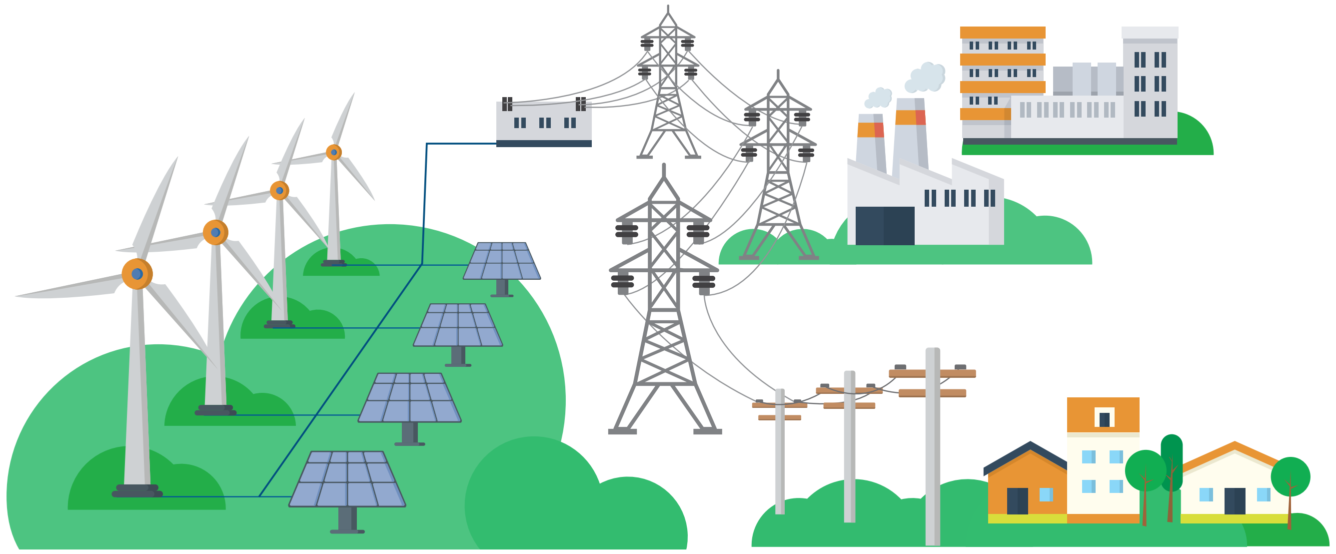
It is important to continue the development of a strong European grid that will fully compensate fluctuations in available wind resources. Assessing wind resources in remote areas along with a strategic planning of the transmission infrastructure are needed to smooth out variations in wind resources, to reduce dependency on capital-intensive energy storage technology and allow a wider penetration of wind power in the energy mix. In particular regarding offshore spatial planning, the challenge is to develop appropriate solutions for grid planning and operation that can connect new facilities cost effectively, manage grid congestion, avoid curtailment and allow for expansion in the future. Along with better grid planning and development, developing more reliable components (e.g. cables) and collection systems within the wind farm will help reduce the costs of wind power.

Improved storage solutions

Enhanced performance of energy storage can offset the variability of wind energy and provide the necessary features to support system stability needs. In addition, the development of demonstration models, business models and fit-to-market products for seasonal storage, such as power-to-x, should be supported. Research is needed to assess the benefits and characteristics of distributed versus centralised storage. On top of this, EU and national regulation should facilitate the development and integration of storage + wind power systems.

Development of hybrid systems

As the system reduces its dependency on large, central, synchronous generators and moves into more variable demand and supply, new concepts of hybrid power systems are gaining importance. Hybrid systems can provide services that so far have been the exclusive domain of conventional units (e.g. black-start). They can also support the stability of the grids. An in-depth analysis of the cost effectiveness of the various hybrid combinations is needed. Demonstration projects should focus on the optimisation strategy for the balance of plant of hybrid systems, as well as revealing the value to different markets and services. Hybrid systems suitable for demonstration include wind + solar, wind + pumped hydro and wind + thermal. In addition, it will be important to understand and assess the variation over time of the component resources with hybrid systems and their interrelationships (i.e. correlations).



OPERATIONS & MAINTENANCE

Operations & maintenance (O&M) is a core competitive sector for most players in wind energy. As such, most of the research work is today exclusively borne by the industry. However, there is added value in publicly funded research on baseline tools and technologies such as enhanced automation, machine learning and next generation robotics, in particular for the offshore environment. As the O&M sector becomes increasingly digital and automated the need for new, strong cybersecurity measures grows ever more important. Research & Innovation will help turn the distributed nature of wind energy into a cybersecurity asset.

The increased use of high quality sensors will create valuable datasets that will allow better insight into the condition and degradation of vital components. New technologies for remote inspection such as advanced condition monitoring systems and remote-controlled vehicles and drones, will reduce maintenance by human intervention to a minimum, thereby cutting the costs and increasing the safety of wind energy O&M.

Key action areas

1. Smart wind farm operations;
   Performance management through better data collection and analysis;
2. Lifetime management;
   Awareness of the environment: external & internal conditions

Smart wind farm operations

Advanced supervisory control at wind farm level will bring two major benefits. Firstly, it will increase total wind farm performance. Secondly, it will reduce fatigue load by mitigating the risks of unwanted dynamic loads and turbine interactions. Smart wind farm control system can be developed to actively monitor the flow field, anticipate wind changes and modify the flow through the wind farm by redirecting the turbine wakes. Today, control systems operate on individual turbine level. Research should focus on developing control systems on a system level. Next generation sensor technologies and integrated data solutions will have to be developed.

Performance management

More research is needed for the development of smart multi-purpose synthetic sensors and big-data analytical tools to enable a holistic monitoring approach. The data gathered will help to identify and prevent root causes of cascading events that contribute to failure modes. This will significantly reduce downtime of turbines. More detailed information on wind turbine performances will allow operators to develop more site-specific lifetime management strategies.

Better knowledge of the properties, degradation and failure mechanisms of materials provides new opportunities for weight and cost reductions, higher reliability and improved manufacture of components and structures. Material science aimed at structures and mechanical and electrical components will allow for both incremental and disruptive innovations.

Lifetime management

It is important to focus on the development of a holistic approach to lifetime extension that includes engineering solutions, digital solutions and human resources. New models of meteorological condition monitoring systems with improved prognostic capability will give better predictions on the remaining lifetime of assets, enabling well-informed and smart lifetime management strategies.

A better understanding of fatigue loads and overall component performance will allow enhanced turbine lifetime management, possible lifetime extension and improved repowering. The enhanced understanding of turbine performances will form the basis of cost analyses informing on the best repowering strategies. The key comparison in these analyses is the cost of replacing key components versus that of a robust upfront design of those components. This means lifetime management will start before wind turbines are installed and enter operational mode. Accurate data cluster analysis will optimise upfront design and enhance turbine lifetime.

Awareness of the environment

A first step to gathering high amounts of relevant data lies in the design of remote sensing strategies. Increased accuracy and robustness of the sensors measuring the performance and health of turbines and their components will form the basis of high quality and low cost data collection. Sensor development is exponential and the wind energy sector will make the most of emerging technologies such as lidar and remote sensing. Coupling sensor data from external conditions with the control system could significantly increase turbine yields and reduce failure rates.

NEXT GENERATION TECHNOLOGIES

In order to develop beyond state-of-art of today and tomorrow, the wind energy sector needs a strong scientific base which involves fundamental and pioneering research. This groundwork has to address the long-term applications and stimulate possible breakthroughs. Digitalisation and big data management are among some of the key challenges. The ability to share data will increase sectoral knowledge and drive the industry forward. However, assessing the sensibility of data is an ongoing challenge.

Cybersecurity is a key priority for the industry. Protecting sensitive data will allow EU companies to retain a competitive edge vis-à-vis non-EU competitors. Future data sharing within the sector itself and beyond will have to be embedded in a strong regulatory framework.

As the designed lifetime of an increasing share of wind power plants is coming to an end, strategies for repowering and decommissioning are gaining in importance. Next generation technology developments should take repowering strategies into consideration, including the development of new materials and the according material recycling solutions.

> The increased use of high quality sensors will create valuable data-sets that will allow better insight in the condition and degradation of vital components.

Key action areas

1. Data driven design and operation methods;
2. Development and validation of high fidelity models;
   Next generation components, materials, towers and support structures;
   Fundamental research into radical and/or disruptive innovations;
3. Material recycling.

Data driven design and operation methods

Today, wind turbines contain hundreds of sensors that monitor thousands of components. The data generated by these sensors provides invaluable information on the condition of the turbine and the external conditions. Using this wealth of data will enable manufacturers to optimise their turbine and component designs and enable operators to revolutionise their control and maintenance strategies, for instance by machine learning. New control concepts will increase performance, reduce loads and limit sound propagation. Enhanced data analysis will allow manufacturers to take a modular approach and design market specific turbines. And yet, the wind energy sector will need to improve its skills in making sense of all this data to fully exploit its potential. To this end, common data sharing and access structures need to be created together with a clear definition of which data can be used for public research.

Development and validation of high fidelity models

In order to optimise the lay-out of wind power plants, further development on modelling wind resources and wind loads at site level is needed. Improved accuracy is needed over a wide range of site conditions, with sufficient resolution in both time and space relevant for wind turbines. New measurement techniques and tools at both wind turbine and wind power plant level are necessary. This should be accompanied by experimental tests that help to address challenges related to turbulences, wake, waves & currents and turbine aeroelastic response, as well as the characterisation of environmental conditions.

Along with the development of intelligent, multi-purpose sensor modules on the asset (condition, structural health) and external conditions, research should focus on creating datasets that can be used to validate models and tools based on life-action turbine data. Components should be validated in test environments that are more representative of the actual operating environment.

Efforts should also focus on developing big data tools that are able to handle hundreds of variables. This requires the creation of a stable and secure framework for sharing high quality data within the wind energy community.

Next generation components, materials, towers and support structures

The use of new advanced materials in the turbine (blades, towers) and supporting structures needs more investigation in order to improve machines' structural integrity and optimise the design margins. Consolidating knowledge on today's materials and investigating the possibilities of new materials such as nano-materials and self-healing materials is key to achieving lighter, stronger, stiffer, and more sustainable and economic structures. Material understanding will also allow for leaner turbine designs. With regard to blades, new coating materials to ward off leading edge erosion are needed. For large rotors, development of superior materials or optimised use of existing materials will help reduce fatigue loading. The development of following new reliable components is needed to take the next leap in turbine design.

- Development of bearings for > 10 MW turbines;
- Superconductor generators;
- Transmission cables (e.g. materials for dynamic HV subsea cable);
- New blade materials and coatings;
- Development of new towers and support structures.

Fundamental research into radical and/or disruptive innovations

Researchers need to look for game changers for wind energy. Out-of-the-box technological advances especially in rotors (e.g. multi-rotor wind turbines) and generators, are a chance for breakthroughs that should not be neglected. To that end, the development of theoretical models for a > 20 MW wind turbine and the viability of new prototypes of airborne wind energy systems should be researched. In addition, solutions should be sought to enable the deployment of wind energy in high potential niche markets such as deep-water, tropical climate, cold climate and erosive environments.

Material recycling

Raw materials and rare earth minerals are becoming scarce due to growing demand. Wind energy accounts for only 3% of global demand, but this will increase in the future and create more (international) competition, most notably from Asia. Retaining access remains of vital importance as the European wind energy industry relies on imports of a number of rare earth minerals, most notably neodymium and dysprosium. Europe must be able to secure a sustainable and affordable supply of these and other raw materials.

At the same time, the sector is committed to further develop industry-wide strategies to re-use and recycle raw materials and rare earth minerals. This will decrease dependency and help decrease the sector's overall ecological footprint. New legislative measures and market mechanisms are needed to stimulate the development of recycling processes, secondary markets and producer responsibility.

With a significant portion of wind energy assets approaching end of life, the establishment of industry-wide strategies for recycling scarce materials from fully-used components will be key in creating a circular economy of significant scale. Blade recycling in particular is an industry priority. Blades contain many fibre reinforced polymer (FRP) thermoset composites that are challenging to recycle. Research is needed to make technological advances in the recycling processes so the mechanical properties of the fibres can be more easily recovered.

OFFSHORE BALANCE OF PLANT

Recent competitive auctions show that the offshore sector has already achieved significant cost reductions and still has a 35% cost reduction potential.[11] Delivering these reductions will require new developments in turbine technology to increase the size and output of wind turbines. However, the most crucial expenditure for the offshore market is the balance of plant, which can account for over 50% of development costs.[12] Balance of plant includes substructures, site access, offshore grid infrastructure, substations, export cables, assembly and installation. It is vital for Europe to innovate in these areas and develop a systemic approach to maintain its current lead in offshore technology.

Key action areas

1. System engineering;
   Offshore grid design;
2. Substructures design;
3. Site conditions.

System engineering
With growing volumes of wind energy flowing into the grids, research will increasingly need to tackle system-level challenges. Two research fields in particular require systemic research: planning offshore wind power plants' connection to the grid and the wind power plant lay-out. On grid infrastructure, a key objective is to create more synergies by interconnecting the grid. This requires analysing the bottlenecks of offshore grid expansion and DC connection costs. Wind power plant level research should focus on the development of dynamic analytical tools to study the relevant physical processes related to turbines, atmosphere and the grid infrastructure on a system level. In addition, there is a need for better understanding of the effects of wind power plants lay-out and operations on individual turbines and vice versa.

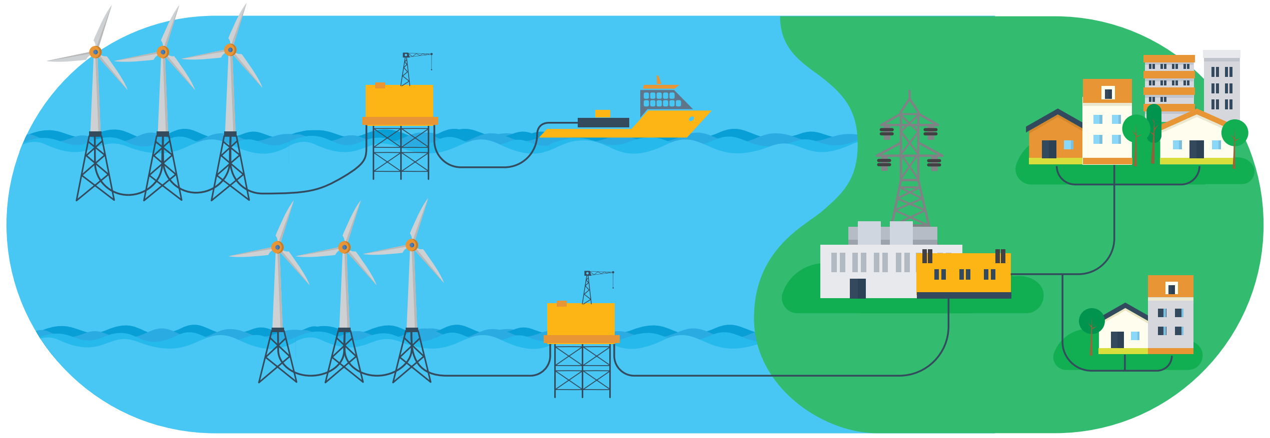
Offshore grid design
The offshore electrical infrastructure is a key cost driver in offshore wind farms. Key research priorities include the analysis of intercable lay-out configurations (DC without substations, improved AC lay-out, low frequencies), installation of DC connections, considering the different connection regimes in each TSO network, and the substation's optimal location (in the foundation, floating, semi-submersible or completely gone). More research is also needed on the control and dynamic performance of operations in those configurations. Tools and models should be developed for system level electrical design, including modelling electrical stress.

On top of this, the development of automated condition monitoring of offshore cables and electric systems, better estimations of remaining lifetime and new repair strategies will reduce downtime and lower costs.

Substructures design
Building larger turbines for the offshore sector entails focussing research on the analysis of optimal foundations for supporting larger turbines. Research studies are needed to assess the crossover point of bottom fixed versus floating systems, including in shallow waters, in terms of economic viability. Among other aspects, dynamic response and load modelling for floating offshore wind turbines needs further analysis.

The development of larger components, modular foundations, vessels including floating installation vessels, port infrastructure and new multi-use substructures (i.e. for various depths) should also be an important focal point for future research.

Site conditions
Minimising the uncertainty and improving the predictability of wind energy, including in complex terrains, and understanding met-ocean and soil interaction are important drivers for reducing the cost of wind energy. In that regard, multiscale environmental modelling and met-ocean modelling and measuring methods need to be further improved. The goal is to develop unified and integrated design analysis tools to enable system-level studies: wind, wave and soil interaction.



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9. IRENA, *The power to change: solar and wind cost reduction potential to 2025*, 2016
10. WindEurope & BVG Associates, *Unleashing Europe's offshore wind potential A new resource assessment*, 2017

FLOATING WIND

Floating offshore wind technology is demonstrating its economic viability and will require a stable and sustainable supply chain to deliver its full potential. While many different floating rotor and platform concepts exist, the sector needs to focus on those concepts that deliver opportunities in terms of scalability and industrialisation needed to drive the floating wind market forward on a global scale. With various, very different concepts still competing, it is clear that no winning concepts have been selected yet. Strong support in research is required to allow the sector to select the best fit-for-purpose concepts.

Key action areas

1. Holistic floating wind turbine system design;
2. Develop sectoral synergies to increase profitability of floating design concepts;
   Establishing a supportive regulatory framework for floating wind power plants;
3. Development of a stable supply chain;
   Preparing floating wind for market uptake and wide scale deployment.

Holistic floating wind turbine system design
In terms of design, the focus should be on turbine-foundation interaction and station keeping systems. The development of models for design, monitoring and testing of anchors and mooring systems will make floating systems more robust. Designs should focus on weight reduction by making efficient use of materials. An industrialised design process that satisfies confidentiality restrictions between the designers and manufacturers of the turbines, substructures and mooring systems needs to be established.

In addition, the cables and underwater cable connectors will also need further investigation. Research & Innovation should develop further knowledge on the connection of inter-array cables in floating arrays, including the lifetime and optimisation of dynamic cables. Also installation methods specific for the floating wind sector will need to be developed. More specifically, research should aim to improve the installation of anchors, moorings and substructure, tow-to-site and upending, and the installation methods in the high seas.

Development of sectoral synergies
It is important to develop new multi-use system operation techniques to increase power demand for offshore wind. In particular the sector should look at exploiting synergies with ocean fish farms for water treatment and the oil & gas sector. Direct power-to-x application combined with floating wind concepts should be assessed.

> **Designs should focus on weight reduction by making efficient use of materials. An industrialised design process that satisfies confidentiality restrictions between the designers and manufacturers of the turbines, substructures and mooring systems needs to be established.**

Establishing a supportive regulatory framework for floating wind power plants
The sector needs to work on the identification of current barriers and bottlenecks that prevent the development of certain floating wind farm concepts. Support for a big European market of several GW spread over 10-15 years has to be established to give the right assurances, so that a market can develop and the industry and supply chain can justify capital investments.

Development of a stable supply chain
Transport and installation of wind turbines are two of the highest capital expenditures and even more so in an far shore environment. Research should focus on supporting the development of a supply chain with installation and hoisting systems suited to floating wind systems. For floating wind in particular, modular design will increase concept reliability and will unlock major cost reduction. Increased research on robotics, automation and the development of autonomous underwater vessels (AUVs) will facilitate the installation and monitoring of anchors and moorings. Industrial configurations in ports and harbors need to be optimised and make sufficient space available for the supply chain to develop.

Preparing floating wind for market uptake and wide scale deployment
Research funding is needed to better define the ability of each floating concept to deal with different sizes of turbines (6 MW, 10 MW, 14 MW). The scaling-up of substructures designs and weights should be studied and standardised. Establishing an EU-wide competition for testing market deployment and upscaling possibilities would be very beneficial to this end.

There is a need to develop deployment models, case studies and market assessments on the best logistic systems for large scale deployment, installation and operation of floating wind farms in various markets and environments. In particular, focusing on installation and access in higher sea states will require new vessels and systems design. The innovations should also allow installations within a wider weather window.

5
FUTURE OUTLOOK

In this Strategic Research & Innovation Agenda we have highlighted the importance of Research & Innovation in wind energy technology and how it will facilitate system integration and achieve further cost reductions. And yet, quantifying *a priori* the exact impact of research is challenging. One cannot dictate what the results or outcomes of research will be, nor how the end products will be used. This unpredictability is an integral part of science and research. Still, we can estimate the overall cost reduction potential for wind energy, based on historical trends and improved understanding of the costs related to operating large scale wind power plants

So what is the cost reduction potential in wind energy? An estimation by IRENA states that costs for onshore and offshore wind will drop by 21% and 14% on a global level respectively with every doubling of cumulative installed capacity.[13] They predict an LCOE reduction of 26% for onshore wind and 35% for offshore wind by 2025.[14] This last number is in line with the sector's own calculations. We expect to see an LCOE of offshore wind power in the 54-65 €/MWh range by 2030. This would be a 50% decrease compared to the average LCOE in 2017. To deliver these cost reductions major technological developments and a clear project pipeline are needed. It is clear that the offshore sector will be a driver for Research & Innovation. Due to the scale of offshore projects, every improvement in offshore technology has a significant impact on the costs.

However, public investments in offshore Research & Innovation should not come at the expense of onshore wind. There is still significant cost reduction potential for onshore wind. In absolute numbers, the onshore sector is still growing more strongly than offshore and with 40 to 80 GW of installed capacity coming to the end of its designed life, the onshore sector will reap the benefits of repowering high quality sites with modern wind turbines. With the right regulatory framework for repowering and lifetime extension the LCoE of onshore wind power will drop significantly.

Source: BVG Associates for WindEurope

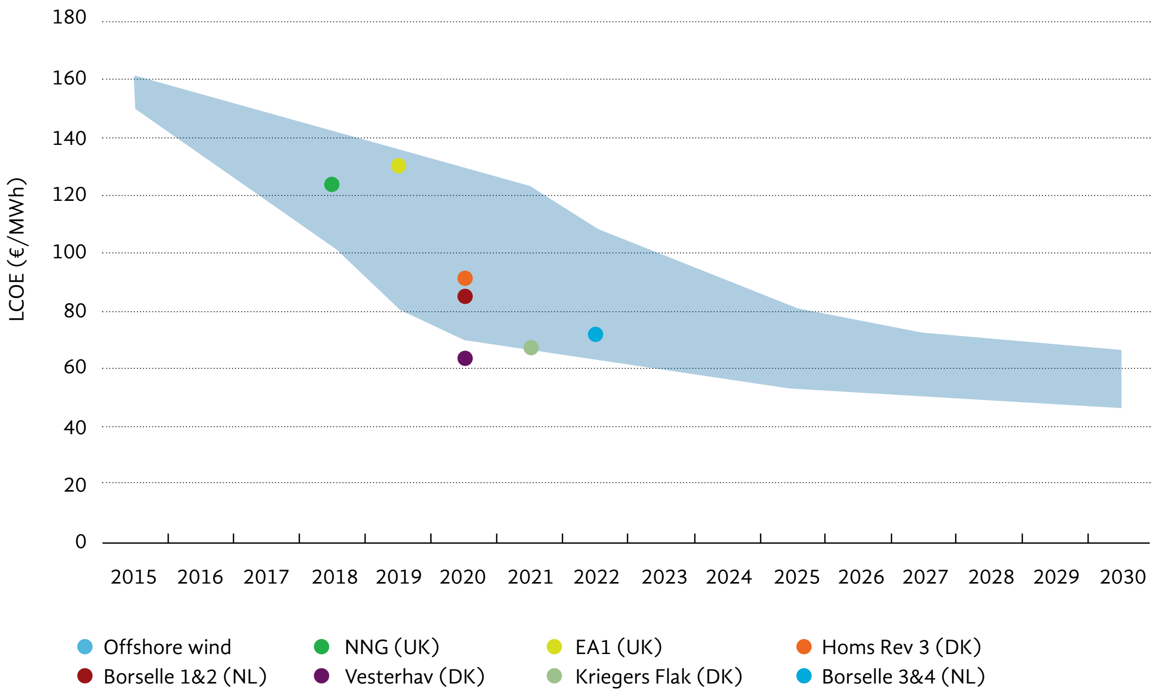

Figure 6 Projected evolution of the LCoE of offshore wind energy in Europe from 2015 to 2030.

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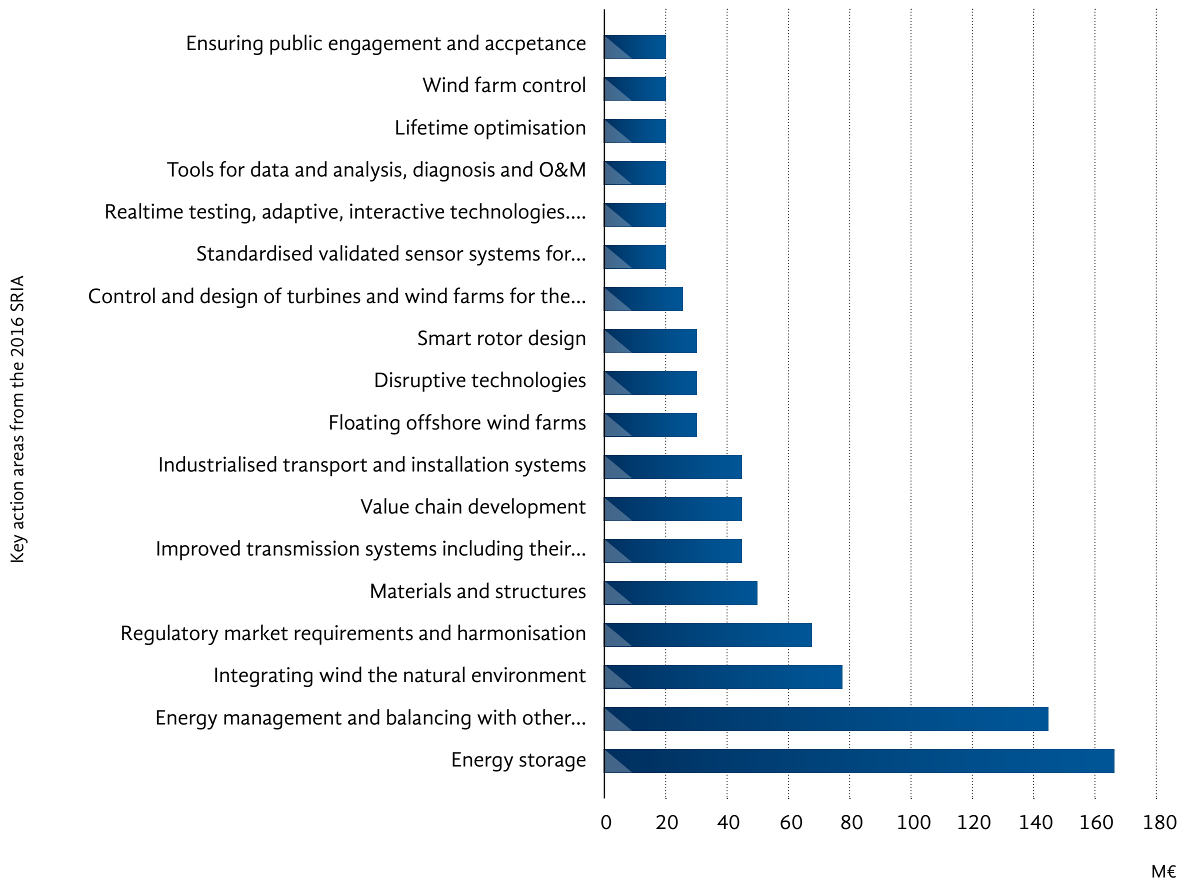
13. IRENA, *Renewable Power Generation costs in 2017*, 2018
14. IRENA, *The power to change: solar and wind cost reduction potential to 2025*, 2016
15. WindEurope & BVG Associates, *Unleashing Europe's offshore wind potential A new resource assessment*, 2017

6
ANNEXES

6.1 WINDEUROPE ANALYSIS OF AUCTION AND TENDER STRIKE PRICES FOR ON- AND OFFSHORE WIND ENERGY IN EUROPE.

ONSHORE				OFFSHORE			
Country	**Year**	**Volume (In MW)**	**SP in EUR**	**Country**	**Year**	**Volume (In MW)**	**SP in EUR**
Italy	2013	442	117,08	**France**	2012	498	226,5
Italy	2013	400	106,40	**France**	2012	450	226,5
Italy	2014	356	91,20	**France**	2012	480	226,5
UK	2015	177	112,65	**France**	2012	496	226,5
UK	2015	104	112,65	**Italy**	2013	30	161,70
UK	2015	96	112,65	**France**	2014	480	220,7
UK	2015	60	112,65	**France**	2014	480	220,7
UK	2015	45	108,19	**UK**	2014	258	181,50
UK	2015	40	109,23	**UK**	2014	1200	169,40
UK	2015	39	112,65	**UK**	2014	660	181,50
UK	2015	37,5	112,65	**UK**	2014	664	169,40
UK	2015	37,5	109,23	**UK**	2014	402	181,50
UK	2015	112,45	112,65	**UK**	2015	714	163,71
Italy	2016	800	66,00	**UK**	2015	448	156,20
Spain	2017	2979	43,00	**Denmark**	2015	400	103,10
Germany	2017	807	57,10	**Netherlands**	2016	700	72,70
Spain	2017	1107	34,00	**Denmark**	2016	350	64,00
Germany	2017	1013	42,80	**Denmark**	2016	600	49,90
Turkey	2017	1000	29,40	**Netherlands**	2016	680	54,50
Netherlands	2017	1138	48	**Germany**	2017	110	60,00
Germany	2017	1000	38,20	**UK**	2017	860	82,31
Turkey	2018	2110	24,05	**UK**	2017	1386	63,31
Turkey	2018	2110	61,10	**UK**	2017	950	63,31
Germany	2018	709	47,30	**Germany**	2018	132	98,30
Germany	2018	709	47,30				
France	2018	508,4	65,40				
Germany	2018	200	46,70				
Germany	2018	700	57,30				
Netherlands	2018	68	67				

6.2 MAXIMUM EU FUNDING ALLOCATION IN HORIZON 2020, WORK PROGRAMME 2018-2020 LINKED TO THE KEY ACTION AREAS OF ETIPWIND SRIA (IN MILLION EUR).



6.3 Overview of the Research & Innovation priorities per pillar

Research & Innovation priorities

	Pillar 1 Grid & system integration	**Pillar 2** Operations & Maintenance	**Pillar 3** Next generation technologies	**Pillar 4** Offshore balance of plant	**Pillar 5** Floating wind
1	Flexibility & ancillary services' markets	Smart wind farm Performance management	Data driven design & operations methods	Systems engineering Offshore grid design	Holistic floating wind turbine design
2	Grid expansion Storage	Lifetime management Awareness of the environment external & internal conditions	High fidelity models Next generation components, materials, towers and support structures Fundamental research into radical & disruptive innovations	Substructures design	Development of sectoral synergies Establishment of a supportive regulatory framework
3	Hybrid systems		Material recycling	Site conditions	Development of a stable supply chain Prepare market uptake and wide scale deployment of floating wind

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 goal 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 RES targets for 2020 and beyond.

ETIP Wind
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PLATFORM ON WIND ENERGY

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