ETIPWind

Roadmap

ETIP Wind
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM ON WIND ENERGY

etipwind.eu

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1
Executive summary

Our climate is undergoing dramatic changes and the effects on our society are becoming more visible and more intense. To halt the disastrous effects of climate change most governments, including the European Union, have pledged to keep global warming well below 2° Celsius by 2100.

Achieving this goal will require a near complete decarbonisation of the energy system and a significant increase in renewable power generation. This energy transition must be swift, sustainable and fair. Wind energy is expected to become the flagship of this transition and provide for at least half of the EU's electricity demand. Deploying wind energy as part of the energy transition will bring several benefits to European citizens and businesses. Carbon emissions will drop, air quality will improve, the environmental impact of the electricity sector will reduce and thousands of new jobs will be created across Europe.

Still, the clean energy transition will require substantial Research & Innovation at all Technology Readiness Levels (TRLs). To deliver on the ambitious climate and energy targets Europe needs strong and fit-for-purpose industrial and research programmes to further develop and improve technology solutions and applications. And to support existing European supply chains. In particular, EU policy should underpin the immediate and large scale deployment of renewable energy technologies by supporting Research & Innovation to:

- improve performance and reduce cost of utility-scale renewable energy production and bring new concepts faster to market;
- enhance sustainability and promote circularity within European industries; and
- accelerate renewables-based electrification (direct and indirect) of hard-to-abate sectors.

Energy experts and policymakers expect wind energy to take a leading role in the power sector, with a total installed capacity of up to 1200 GW by 2050. Such ambitious targets need to be supported with a dedicated industrial policy on wind energy. Wind energy holds a unique place in the European industrial fabric. It is at the same time a high-tech green and heavy manufacturing industry. Innovation and technology development play a big part in the success of wind energy in Europe and further technology advancement will be essential for a successful and just energy transition.

To sustain this trend the industry needs continued support to design and manufacture new component structures and materials and develop new high precision manufacturing lines suited to mass production of larger and more efficient turbines. New materials and multi-material solutions should reduce weight, increase durability and improve mechanical performance.

At the same time, the wind industry is committed to sustainable production by enhancing circularity and developing new materials. Improved and more cost effective recycling technologies will further reduce the ecological footprint of the sector. Critical materials such as glass and carbon fibres can be recovered and re-used in a circular economy. Research into new, more recyclable materials will reduce EU's dependence on rare earths and other critical raw materials.

Targeted R&I support will also strengthen the leading role of the European industry in the global market. Competition from non-EU players is rapidly increasing and the associated cost reduction pressures have a big impact on revenues and employment, especially in the European supply chain.

ETIPWind therefore recommends European and national governments to align their R&I funding programmes with the priorities laid out in this report.

2

Immediate action and scale required for energy transition

Climate change has detrimental effects on Europe's society and economy. To stop climate change the EU has committed to help keep global warming under 2° Celsius and aiming for 1.5° Celsius and is a party to the Paris Agreement. As a result, the EU has pledged to reduce CO_2 emissions by 2050 to at least 80% compared to 1990 levels.[1] And the new Commission President Ursula Von Der Leyen wants Europe to become the first climate-neutral continent.[2] Significant reductions have been achieved in the past, but in recent years emission levels have plateaued.[3] The challenge thus remains acute.

To reach the goals of the Paris Agreement, Europe must decarbonise its energy system. Polluting fossil fuels need to be phased out and replaced by renewable energy sources. Renewables-based electrification is the best option for cost-effective and efficient decarbonisation. However, today electricity accounts for just 24% of Europe's total energy use and renewables provide just 30%.

In 2018 the European Commission launched its communication on the Long Term Strategy for decarbonisation. As part of this Strategy the European Commission modelled several decarbonisation pathways. In all of them they expect electricity to meet between 41% and 53% of total energy demand in Europe by 2050. And wind energy alone would provide more than half of that electricity. This equals to a total installed capacity of between 700 and 1,200 GW.[4]

WindEurope estimates that a direct electrification rate of 62% by 2050 will see the EU comply with the Paris Agreement. In this scenario electricity demand will nearly double, but as electricity is a highly efficient energy carrier, Europe's total energy demand will reduce.[5]

The European Commission's scenarios are matched and even surpassed by those of EURELECTRIC, the association of the electricity industry. They foresee a much higher electrification rate with a similar share of wind energy. Installed capacity for wind would be between 900 and 1,100 GW by 2050[6]. See figure 1 for more details on the scenarios.

	Baseline (2017)	WindEurope Breaking New Ground Paris scenario	EURELECTRIC Decarbonisation Pathway Scenario 3	European Commission 1.5 TECH scenario
Timing	2017	2050	2050	2050
GHG reduction	27%	90%	95%	100%
Electrification rate	24%	62%	60%	50%
Electricity demand	3,650 TWh	5,450 TWh	4,739 TWh	3,989 TWh
Wind energy installed capacity	169 GW	840 GW	1,100 GW	1,210 GW

Figure 1 Different scenarios to reach an energy system compliant with the Paris Agreement by 2050

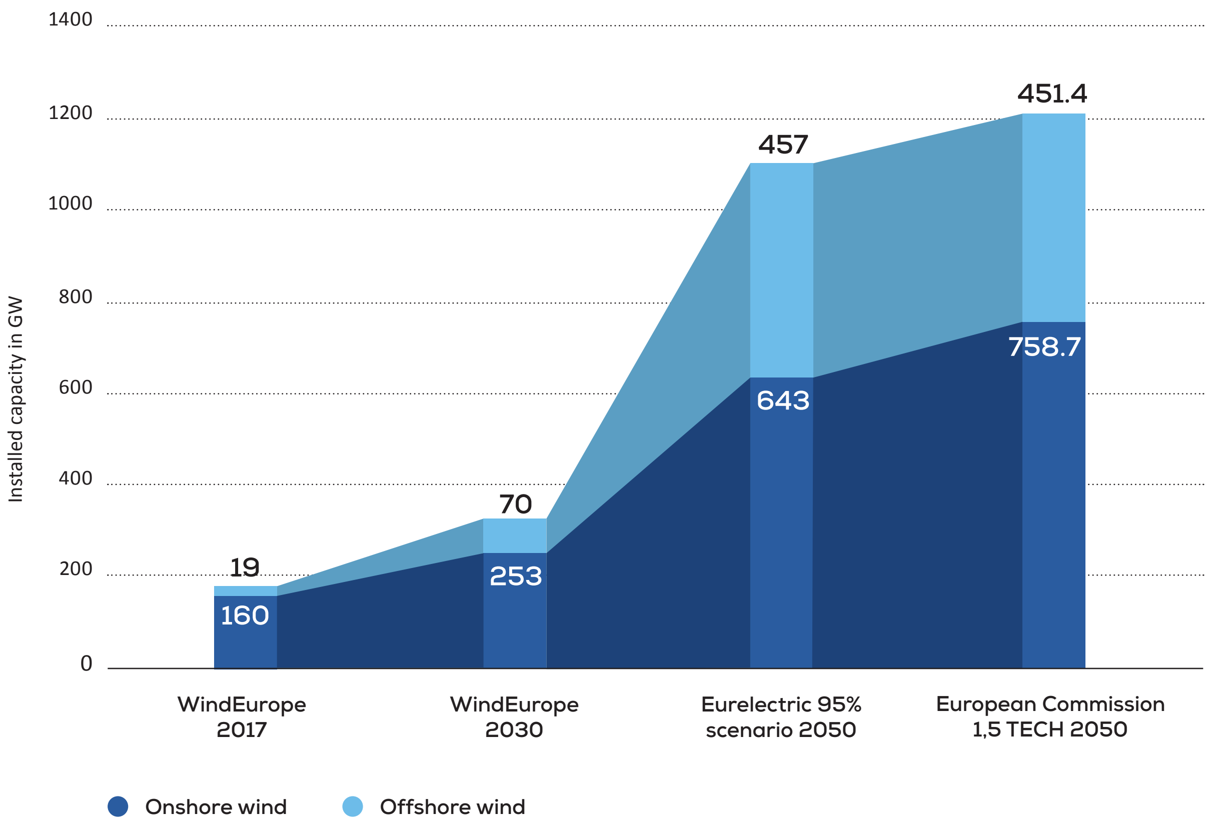


Figure 2 Scenarios for wind energy deployment

The time to act is now

Urgent action is required to deliver the energy transition. At a global level renewable power production needs to more than double just to maintain emissions level, let alone reduce them.[7] However, many governments struggle to formulate an adequate response to this challenge. More focused support is needed but essential investments and political decision are often postponed due to short-term thinking.[8] Inaction only further increases the cost of the energy transition.[9]

Fossil fuel subsidies are a good example of this inaction. In spite of political rhetoric, significant cost reduction in renewable power generation and overwhelming popular support for renewable energies, fossil fuel subsidies have not declined.[10,11] On a global level, the International Monetary Fund (IMF) estimates almost $5,000 billion was spent on fossil fuel subsidies in 2017 alone.[12]

Also in Europe fossil fuel subsidies remained stable and even increased from 2008 to 2016 with €1.8 billion. In 2016, €55 billion was spent in support of fossil fuels and €75 billion went to renewables. In other words, for every Euro in support of renewables, 73 cents went to support polluting fossil fuels.[13] And this while subsidies for renewables do make an impact. Every Euro of public support to the wind energy sector helped avoid 8 kilogrammes of CO_2 emissions. From 2011 to 2016 wind energy helped avoid 819 million tonnes of CO_2 emissions.[14]

> At a global level renewable power production needs to more than double just to maintain emissions level, let alone reduce them.

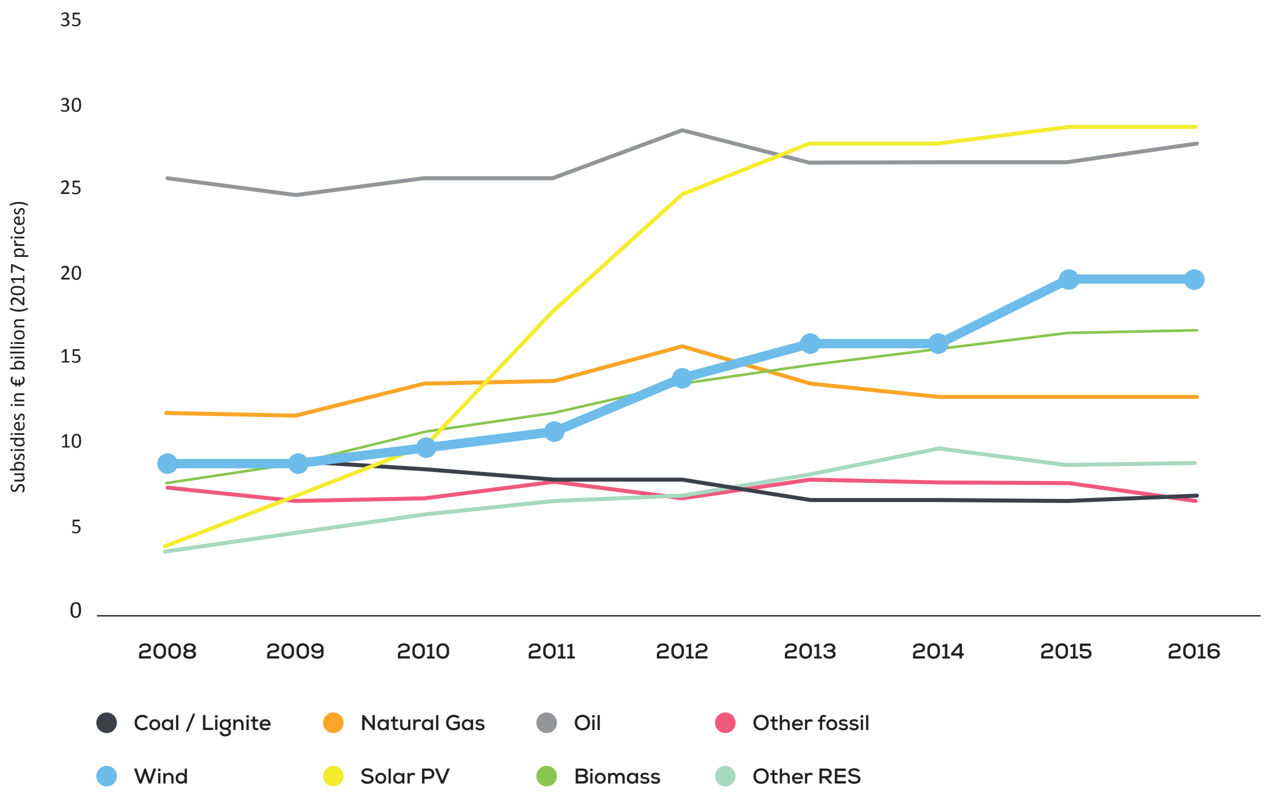


Figure 3 Evolution of energy subsidies in the European Union 2008 - 2016

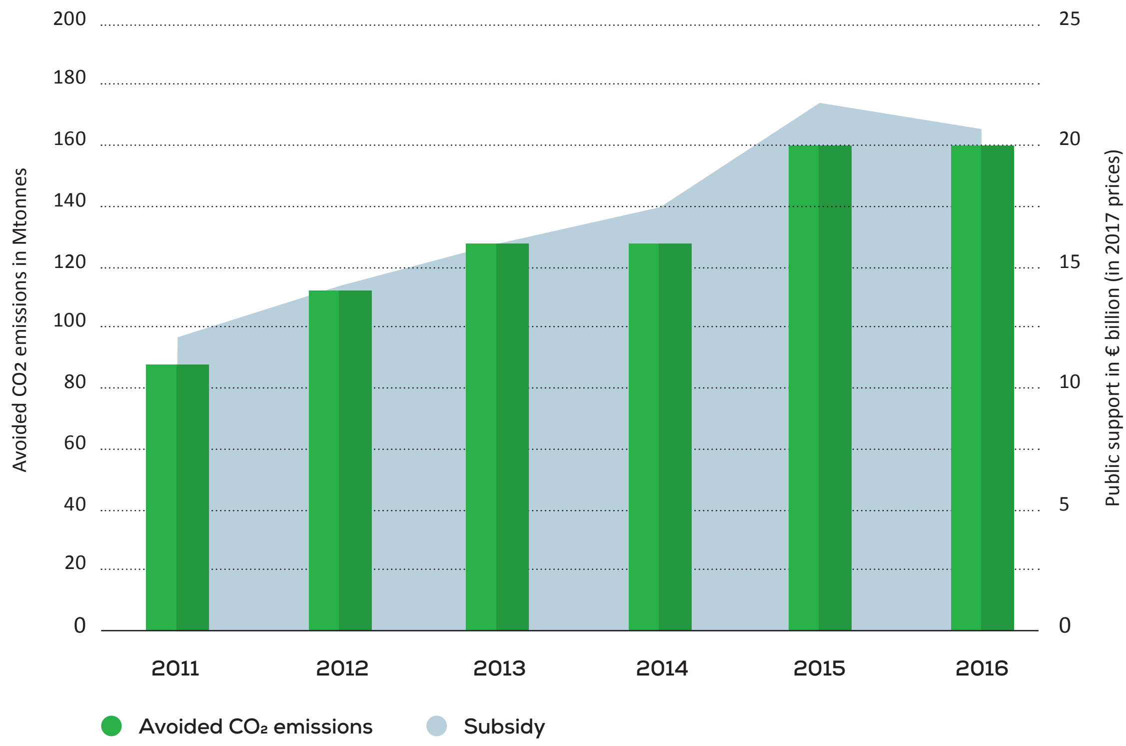


Figure 4 Wind energy public support and avoided CO_2 emissions

A robust all-encompassing policy framework for a successful energy transition

The insufficient sense of urgency and distribution of limited resources severely limits the success of the energy transition and puts Europe on a dangerous path of no return. Transforming the energy system requires significant investments in generation and transmission infrastructure. These investments have significant lead times, so the time to act is now.

The European institutions play a vital role in delivering the energy transition. Powering Europe's economy with renewable electricity requires immediate and large scale deployment of renewable energy technologies. The EU should lead the way by steering investments towards high impact technologies and supporting Member States that heavily depend on the fossil fuel economy with an inclusive clean energy transition based on renewable energy sources.

To deliver on the ambitious targets for 2050, Europe needs strong industrial and innovation policies that set the right market conditions and investment signals, lower the risk of investment and support existing European supply chains. It also requires allocating substantial and targeted budgets for R&I in wind turbine technology and the wider system integration of renewables.

Place Europe ahead in the global renewable energy market

R&I support is also essential to ensure Europe retains its global leadership in renewable energy technology. In the wind sector European companies were able to capitalise on their first mover advantage and are still leading in the global wind energy market. In recent years European turbine manufacturers have had an average global market share of 45%.[15]

However, European leadership should not be taken for granted. Increased global interest in wind energy solutions has made European manufacturers increasingly dependent on revenues from non-EU markets (sometimes up to 50%).[16] And growth in the non-EU markets is expected to accelerate exponentially.[17] This makes European companies more vulnerable to international competition and directly puts European jobs and revenues at risk.

Investments in optimising the European supply chain and improving the manufacturing capabilities of European companies will be essential to retain a strong European wind industry in Europe and the global market. Policymakers should acknowledge the renewable energy sector is a sector of strategic importance to the EU.

We call for an European strategic industrial policy to support the EU's global leadership in renewables. Policy instruments such as strategic value chains and Important Projects of Common European Interest should be coupled with robust R&I policy and programmes such as Horizon Europe and the Emissions Trading Scheme (ETS) Innovation Fund play a vital role to ensure lasting technological leadership.

R&I support from these programmes should focus on technologies and tools that:

- Improve performance and reduce costs of utility-scale renewable energy production and bring new concepts faster to market;
- Facilitate large scale integration of variable renewables in the existing energy system;
- Prepare the build-out of a more decentralised and distributed grid;
- Enhance sustainability and promote circularity within European industries; and
- Accelerate the renewables-based electrification (direct and indirect) of hard-to-abate sectors.

The next chapter spells out the specific research actions that will allow the European wind industry to meet the ambitions of European policymakers and citizens, to sustain its cost competitiveness compared to other energy sources and keep Europe as global leader in wind energy technology. The priorities build on the recommendations from the 2018 ETIPWind Strategic Research & Innovation Agenda and provide an in-depth perspective on the 5 pillars of wind energy R&I. As there are more than 60 research actions, only a summary is presented in this report. For the full details, please visit https://etipwind.eu/.

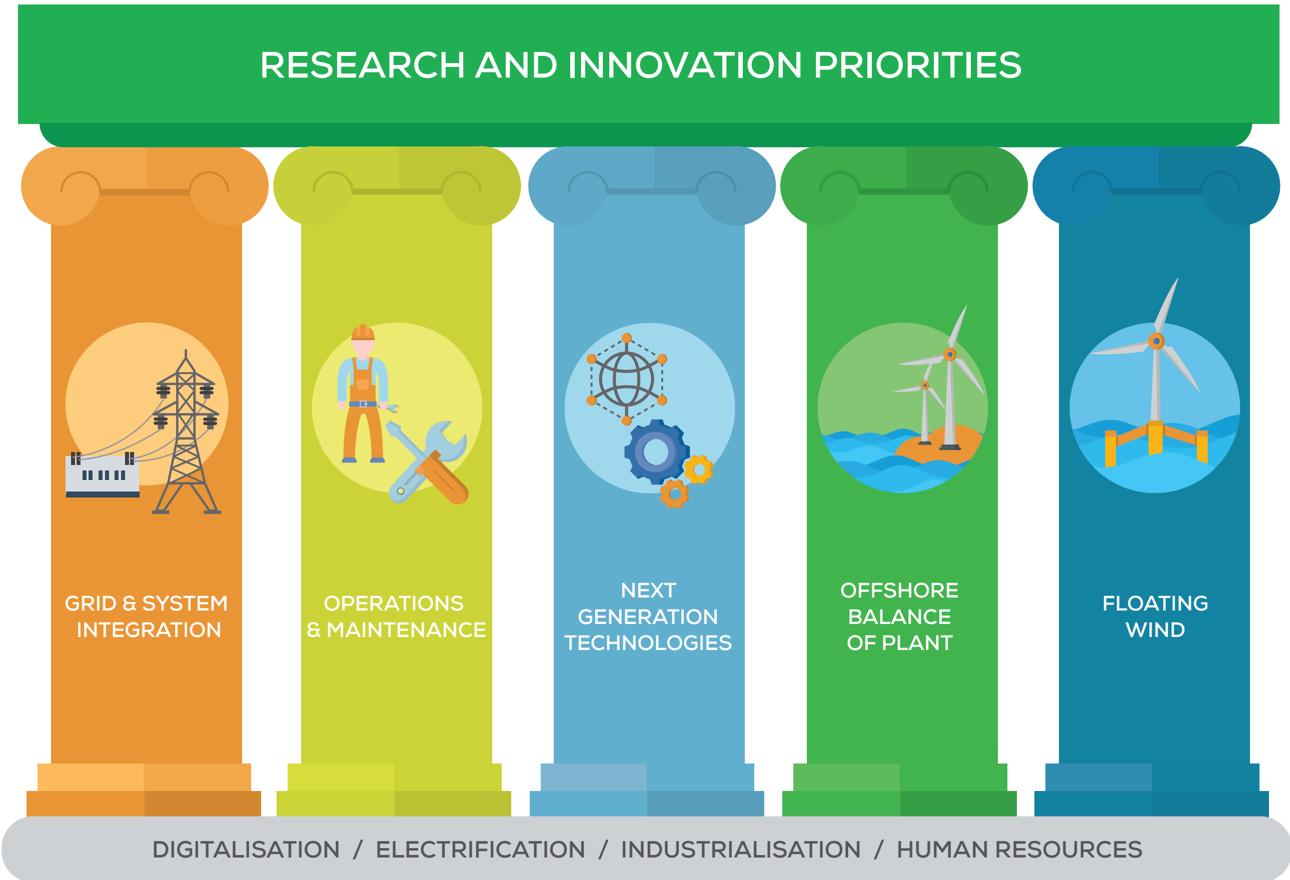


Figure 5 The 5 pillars of wind energy Research & Innovation

3

Research & Innovation priorities 2020-2027

Technology Roadmap

High priority

Medium priority

Low priority

- Grid & system integration
- Operations & maintenance
- Next generation technologies
- Offshore balance of plant
- Floating offshore wind
- Skills & human resources

Short-term 2020-2022

High priority

- Integrated forecasting of power production & demand
- Short-term energy storage

- Lifetime assesment and condition monitoring
- Digital tools for control and monitoring

- Development and validation of components & materials
- Blade recycling demonstration
- Integrating wind energy in the surrounding natural and social environment

- Lean production
- Validation of design tools
- Mooring and anchors
- Dynamic electric cables
- Control methods

- Expand and harmonise wind energy teaching in Europe

Medium priority

- Long-term energy storage

- Robotic inspection and repair methods

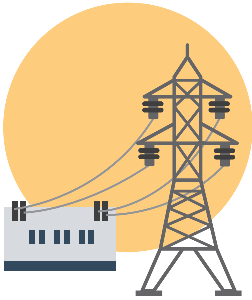
- New transportation methods for large components

- Data availability & sharing
- Serial production – analysis of substructure production processes

Low priority

- Multi-cultured wind farms
- Modelling future system needs

Medium-term 2023-2024	Long-term 2025-2027
• Optimising transmission infrastructure	• Stable system with 100% RES
• Dynamic cable repair solutions • Digital solutions for smart operations • Predicting environmental parameters	
• Development of sustainable materials • Standards • Manufacturing processes	• Recycling methods for materials and components
• Cabling and connections	• Cross-industry agreement and standards • Integrated optimised design plan • Verification of methods and procedures
• Boost wind energy higher education	
• Quantification of system services • Sustainable hybrid solutions	
• Decommissioning strategies and technology • Solutions for operating in extreme conditions	
• Sensor technologies, diagnostics and response • Next generation generators • Noise reduction • Reliability of components	• Disruptive technologies
• Material durability and protection	
• Integrated design process in supply chain	• Park level control
• Joint academia-industry educational programmes	
	• Supply chain logistics (decommissioning)
• Floating installation, assembly and heavy maintenance	



Grid & system integration

Wind energy has become a mainstream source of power generation, meeting 14% of Europe's power demand.[18] It will become the backbone of Europe's energy system with estimations for the share of wind energy in the power mix ranging from 30% to 50% and more by 2050.[19] The International Energy Agency (IEA) estimates wind will become the largest power source in Europe by 2027.[20]

A renewables-based power system will be distinctly different from the current system. Research is needed to identify and quantify the stability needs of the future power system and innovative technologies will help establish a new grid architecture that values flexibility, efficiency and reliability.

To integrate these vast amounts of variable renewable energy in just a few decades will require a new range of technologies and solutions for system operators, as well as an updated market design. In particular, innovation is needed to facilitate communication between wind power plants and system operators, to develop more robust technologies for grid integration and to transfer wind power quickly, efficiently and safely from the site of production to wherever it is needed.

Apart from including more variable renewable energy sources, the future electricity system will also be much larger than the current one. As shown earlier the electricity demand is set to at least double by 2050. Development of enabling technologies for direct and indirect electrification in other sectors will maximise the decarbonisation potential of green renewable power. Short- and long-term storage solutions will help overcome periods of low natural resources without relying on polluting fossil fuels.

Challenge 1

Preparing the system for 100% of renewables

As more and more Member States will increasingly rely on variable renewables to decarbonise their economies, the power system will undergo a transformation. Currently renewable power operators are asked to emulate conventional power plants. This is an ineffective use of the resources and often leads to additional costs. There will be a shift from demanding renewables to adapt to the existing system to demanding the existing system adapts to renewables.

This shifting notion of how the power system works will raise some significant challenges. As more distributed generation will enter the grid, it is essential to enhance and accelerate communication and coordination between all actors including plant operators, system operators (TSOs/DSOs) and consumers. With increased digital communication, data management and cybersecurity become paramount. In a converter-based grid, optimising the use of existing grid infrastructure and developing High Voltage Direct Current (HVDC) technology and grid-forming capabilities will be essential. In addition, hybrid projects and virtual power plants need to be demonstrated at larger scale and across Europe.

Challenge 2

Flexibility at the heart of a 100% renewable system

To decarbonise the EU economy more variable renewable energy power plants will be installed and wind is set to become the largest source of electricity in Europe. In the short term, this will require grid operators to add more flexibility to the grid. A lack of flexibility in hardware and software at system level would lead to unnecessary and unsustainable costs. The need for flexibility is present at various time intervals. Real-time flexibility is needed to stabilise the system, short-term solutions to balance the system and sustaining system adequacy will require solutions operable on the long term.[21]

Wind farm operators can also be expected to take on more and different responsibilities towards grid management by providing ancillary services, and to develop new solutions to decouple energy production from energy harvesting, so that power can be provided to the system when resources are low. This requires innovation in short-term and seasonal storage, multi-cultured wind farms (wind farms with more than 1 type of turbine installed) and hybrid systems. At the same time, more accurate and precise forecasting of both power production and demand well help to better link demand and production and ensure optimal use of available resources.

Wider regulatory requirements

Whilst new technologies will help manage an energy system with high shares of renewables, the capabilities to absorb high shares of wind energy are more determined by economics and market design. Technical constraints exist, but market barriers and existing operating paradigms and principles are often more restrictive. To ensure optimal integration of wind energy in the system, policymakers should tackle following regulatory issues for a sound implementation of the Clean Energy Package:

- Increase flexibility in the electricity market design so that it can integrate new technologies and adapt to their characteristics (e.g. by updating the market, operation and connection codes), in line with article 59§2 and article 60 of the recently adopted Electricity Regulation;[22]
- Establish effective intraday markets so that electricity can be traded as close to the moment of production as possible, in line with article 6§4 of the Electricity regulation;[23]
- Enable daily procurement of balancing reserves to allow variable resources to participate and products should be short to reflect real-time variability as stated in Annex 1 of the Electricity Regulation;[24] and
- Promote virtual aggregation of different power generation technologies as a standard practice, rather than an exception.

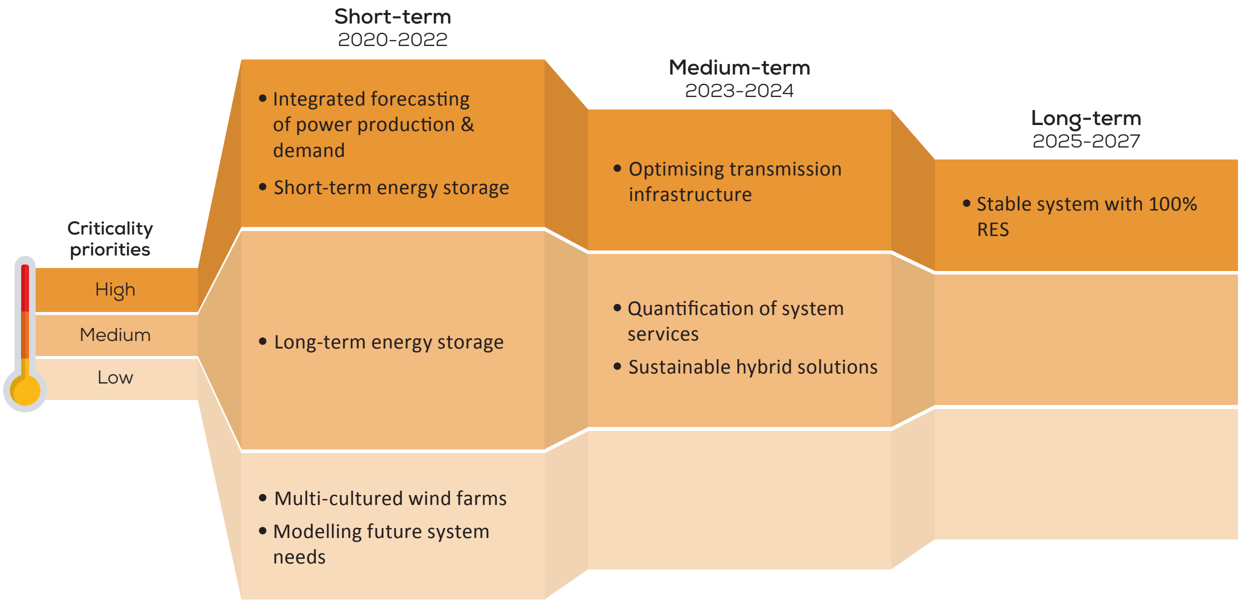


Figure 6 Research & Innovation action areas for grid & system integration

Operations & maintenance

Operations & maintenance (O&M) lies at the core of wind energy technologies. The O&M sector is a highly competitive arena for the wind energy industry. Next to the wind turbine manufacturers, there are now many specialised companies providing O&M services. This means that for manufacturers the service contracts only make up between 15 and 20% of the annual revenues.[25] At the same time, it is estimated that operational costs for wind projects can account for up to 20% of the total budget.[26]

As such, technology development in O&M is mostly covered by the private sector. Still there is a need for more research in transversal areas such as automation, robotics and big data analytics. Cybersecurity will grow in importance as the wind sector becomes increasingly reliant on digital technologies to communicate and integrate with other actors in the energy system.

With regards to operations, the focus for research and innovation should be on improving the overall performance of the technology at the lowest possible cost (seen from a lifetime point of view). With regard to maintenance, research should focus on improving condition monitoring and reducing manned interventions to a bare minimum (e.g. by enhancing automated repair methods).

Challenge 1

Optimising operations

Wind turbines are exposed to a wide variety of weather phenomena including extreme winds, lightning, frost and heat. These external conditions are highly variable and turbines are built to endure them throughout their lifetime. However, due to these ever-changing external conditions, wind turbines experience a wide range of changing loads. These loads build up stress levels in key components such as blades and generators.

More accurate understanding of the stress levels in critical components is vital to ensure wind turbines operate at their optimum capacity. Better performance management will allow the asset to be operational for a longer period of time and will increase the value of each MWh produced. Operators will need to connect and aggregate real time data from turbine components. The amount of data gathered for analysis will require new big data analytic techniques and solutions using the development of artificial intelligence.

Challenge 2

Increasing energy availability

Operating wind power plants is very different from operating conventional energy plants. Wind power plants often comprise multiple connected, yet independent assets that are geographically distributed. So wind operations come with a unique set of challenges, of which we underline two.

Firstly, unlike conventional power plants, wind turbines are often installed in more remote and less densely populated areas. This often makes it difficult to get the people, materials and components to the asset on time, especially when an unexpected error occurs. The sector's priority is to prevent unexpected failure modes, but R&I in digital solutions and remote sensing will help increase the active range of O&M personnel in case an error occurs.

Secondly, wind farm operators and portfolio managers also operate and maintain a large amount of assets compared to conventional power plant operators. More research into digital portfolio management systems will help ensure operators can optimise power production at fleet level rather than at individual turbine level. In addition, as more and more wind turbines assets are installed, operators will also need to develop comprehensive decommissioning strategies to deal with the number and variety of assets that will reach the end of their designed life in the coming years. Decommissioning strategies and technology need further development.

Wider regulatory requirements

Standardisation and harmonisation of regulatory requirements will simplify manufacturing, installation and operational procedures and bring additional cost reductions. This is especially true for the offshore wind sector. Based on the recommendations of the North Seas Energy Forum, the wind energy sector calls for:

- Standard recognition and/or harmonisation of certification standards for crew and technicians and the alignment of crew requirements;
- Standard definition, recognition and/or harmonisation of certification standards for waste maritime operations; and
- More flexible regulatory requirements for park layout to allow optimal yields. In particular, straight lines should be avoided.

As 20 GW of installed capacity will reach the end of its designed life by 2022, decommissioning and dismantling will become an essential part of the wind energy business.[27] To ensure safe and cost-effective decommissioning across Europe, we call for policymakers to:

- Standardise and align the requirements for wind farm developers across Europe with sector developments.

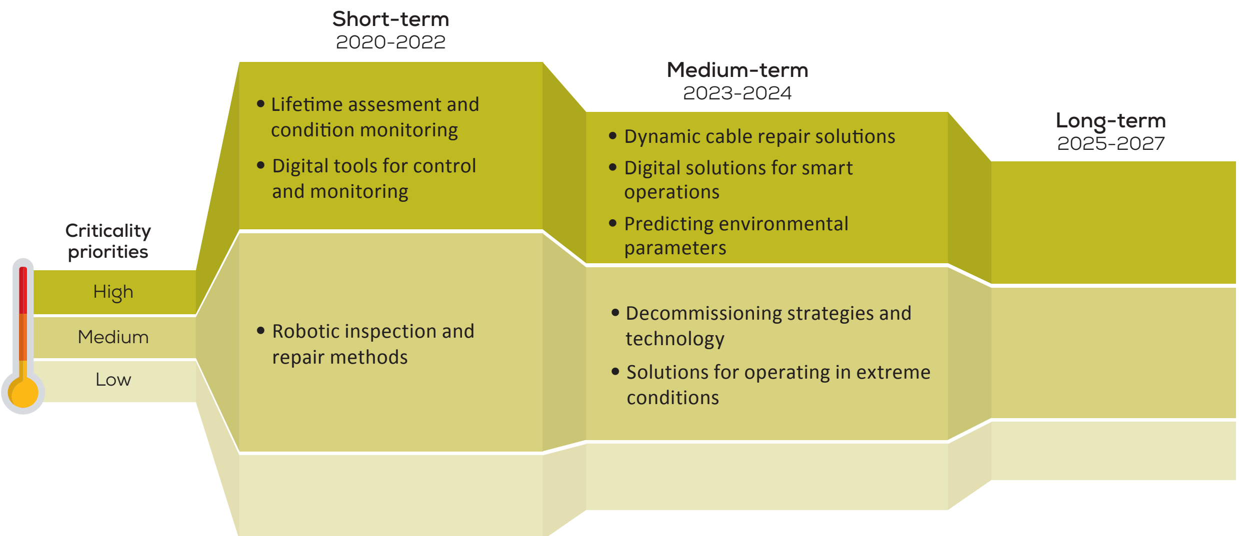


Figure 7 Research & Innovation action areas for operations & maintenance

Next generation technologies

Today wind energy is the cheapest source of new installed power capacity in many regions of Europe. Still, governments and consumers expect wind energy to continue decreasing costs to accelerate the shift away from fossil fuels. The sector is under continuous pressure to deliver high quality end products at low costs.

This pressure is exacerbated by the following aspects. Firstly, the new auction system, which has helped drive down costs for wind energy rapidly, has also reduced the operational margins of the supply chain. Secondly, non-EU suppliers are now able to provide high quality materials and components and outprice the European supply chain. Thirdly, restrictive trade policies increase the price of materials such as steel and glass fibre used in key components.

The European wind industry is competitive mostly due to its excellence. To retain a competitive advantage the sector continuously needs to develop and market the best technology available. This requires significant investments in R&I, and given the cost reduction pressures, companies need stable and secure revenues to sustain investments in technology development.

However, development of new technology is not a straightforward line. R&I is by definition risky and uncertain and the maturing wind industry cannot take on all the risk by itself. EU support for R&I in wind energy plays a pivotal role to help the energy sector nurture radical solutions that challenge the status quo. The development of new breakthrough applications and technologies will help establish wind energy at the heart of the energy transition and boost the competitiveness of the European wind industry in the global market.

Challenge 1

Cost competitiveness of the EU wind industry

Wind energy holds a unique place in the European industrial fabric. It is at the same time a high-tech green and heavy manufacturing industry. Innovation and technology development plays a big part in the success of wind energy in Europe and EU funding for R&I acted as a catalyst for the impressive cost reductions in the sector.

To sustain this trend the industry needs continued support to innovate, design and manufacture new component structures and materials and to develop new high precision manufacturing lines suited to the mass production of larger and more efficient turbines. Research and development of new materials and/or multi-material solutions should reduce component weight, increase durability and improve mechanical performance. Transportation and installation technology also needs to be improved and scaled up to match the development of bigger wind turbines in the coming years.

Challenge 2

Towards a 100% sustainable wind energy sector

To ensure Europe will lead the way in a sustainable energy transition, the EU must prioritise R&I funding to diversify and scale up recycling technologies as part of the next R&I framework programme, Horizon Europe. Most wind turbine components such as the foundation, tower and gearbox are recyclable, making wind turbines 85% to 90% recyclable. However, rotor blades represent a specific challenge due the composite materials used. Large scale demonstrations of and further innovation in recycling technologies is needed to recover critical materials such as glass or carbon fibres and magnetic materials.

In addition to recycling solutions, new materials will need to be developed. These materials will have to be lighter, more durable and more recyclable to increase sustainability and reduce the EU's dependence on imports of rare earth minerals and other critical raw materials.

Wider regulatory requirements

To continue cost reductions and sustain the European manufacturing base, R&I support to wind energy is vital, but not sufficient. A wider and more holistic approach is needed to ensure the European wind industry can meet the ambitions of policymakers and deliver low-cost energy to consumers. Therefore, we call for policymakers to:

- Establish a European industrial policy for wind and other renewables focused on:
  - Development of high precision manufacturing lines for wind turbine components;
  - Further integration of circularity in the renewables sector; and
  - Development of new digital solutions and applications.
- Ensure Europe retains access to high-quality raw materials and components by:
  - Promoting free trade policy with non-EU markets;
  - Supporting innovation in the European supply chain so that materials and components (e.g. high-grade grain-oriented electrical steel) manufactured in Europe meet the necessary quality and eco-design requirements; and
  - Establishing a new regulatory framework for heavy freight transportation to ease transportation of very large components.

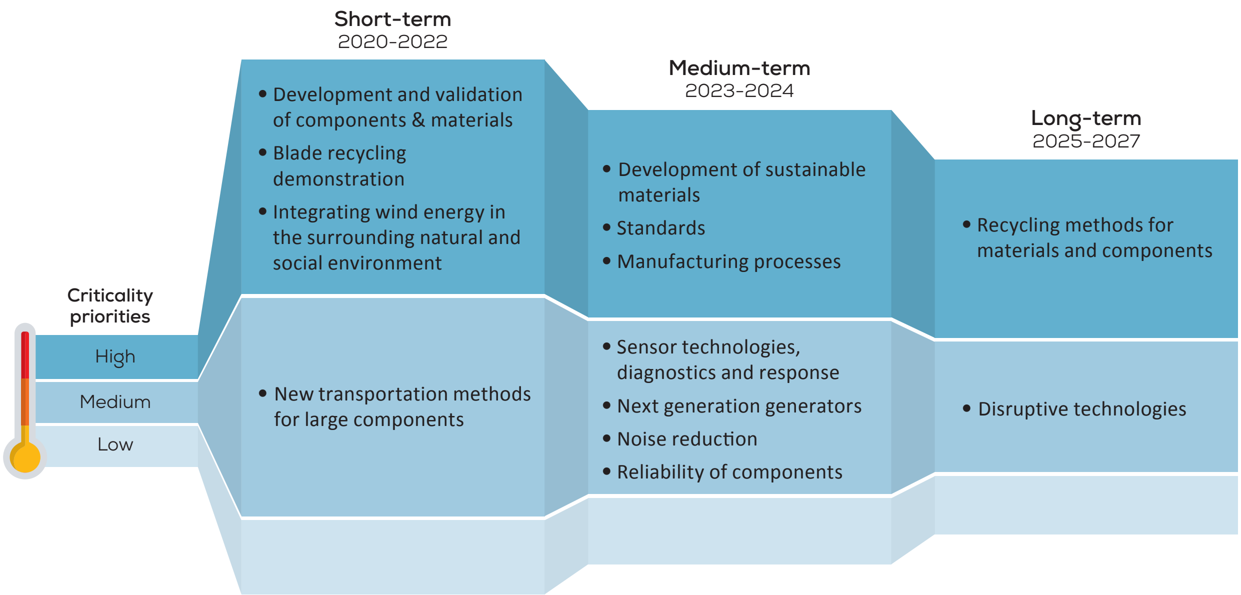


Figure 8 Research & Innovation action areas for next generation technologies

Offshore balance of plant

The sector's push towards developing offshore wind is driven by two considerations. Firstly, there are better wind conditions at sea. The winds are stronger and the air is denser. Secondly, going offshore also allows for larger turbines to be installed and run more operative hours. Whilst cost are higher to develop offshore, offshore wind farms deliver green bulk power and present good value for money. In recent years the sector has seen significant cost reductions from 150 €/MWh to 65 €/MWh or less.[28]

The balance of plant cost is the most challenging of problems and consists of offshore foundations, cabling and transformer platforms. In addition, it is linked to the optimisation of support ports and fit-for-purpose installation and cabling vessels. Balance of plant can account for as much as 50% of the offshore wind farm cost and is one of the most difficult areas to yield cost savings.

Offshore wind costs are higher than onshore in large part due to the high cost of offshore foundations, the hostile maritime environment and the scale. Not only are the turbines significantly larger and heavier, the wind farms themselves are also bigger. The average nominal capacity of an offshore wind farm increased from 79.6 MW in 2007 to 561 MW in 2018. This poses significant challenges with regard to logistics, installation and maintenance.

Challenge 1

Installing large volumes offshore

In offshore wind, sector size matters. Offshore wind turbines installed today are already the largest rotating machines in the world and the sector continues to develop bigger turbines, with 12-15 MW turbines due to reach the market in the next decade. These larger and heavier wind turbines require more space, deeper draughts and stronger installation vessels and cranes. The current stock of installation vessels is unable to install the designed 15 MW turbines. Innovative concepts and designs are needed to develop next generation vessels able to lift over 1,000 tonnes.

Cabling is essential to the success of offshore wind. Without solid electrical infrastructure, offshore wind farms are rendered idle. Cable faults cause prolonged disconnections that result in significant loss of production and revenue and often it takes weeks to repair. Cable faults affect both the inter-array cables connecting the turbines and the export cable from the wind farm to the grid connection point onshore.

Twisting, overloading and erosion of the seabed cover are some of the main causes of cable failures. The latter causes the cables to sway in ocean currents creating unforeseen loads to the already connected cables. Better methods to test the integrity of cables post-production, post-transportation and post-installation are needed to limit faults and avoid high repair costs.

Challenge 2

Common methodology for integrated offshore wind farm design and development

To reach large-scale commercialisation, the industry has identified several potential bottlenecks in the supply chain that could hinder offshore wind development in the coming years. The major issues relate to ports infrastructure requirements for serial production, dynamic export cables, and auxiliary equipment to withstand electric loads, as well as operations and maintenance technology.

The wind industry and its supply chain should develop logistics models for offshore wind and identify common installation technologies and manufacturing requirements. Bigger vessels, with cranes able to lift heavier components, will alter the existing logistic flow for assembly and installation of wind turbines.

In addition, standardisation in foundation systems will facilitate offshore wind development. Common junction boxes to ease and standardise termination of inter-array cables will significantly ease installation. This would avoid costly faults and allow the same foundation systems to be used by different manufacturers, enlarging the market for the European supply chain. R&I should help find new solutions and set better standards for corrosion protection for jacket foundations.

Wider regulatory requirements

Offshore wind farms are multi-billion euro projects and such investments require extensive and careful planning throughout the entire supply chain. A stable market outlook will be essential to unlock further investment in technology and R&I, skill development and jobs. Policymakers can improve investment clarity by:

- Integrating ambitious deployment plans for offshore wind to 2030 and beyond in their National Energy and Climate Plans;
- Stepping up cooperation in maritime spatial planning, cumulative environmental impact assessments and offshore grid connections (including interconnectors and hybrid projects);
- Coordinating the timeline of tenders across the various sea basins; and
- Increasing investments in port infrastructure and the maritime supply chain.

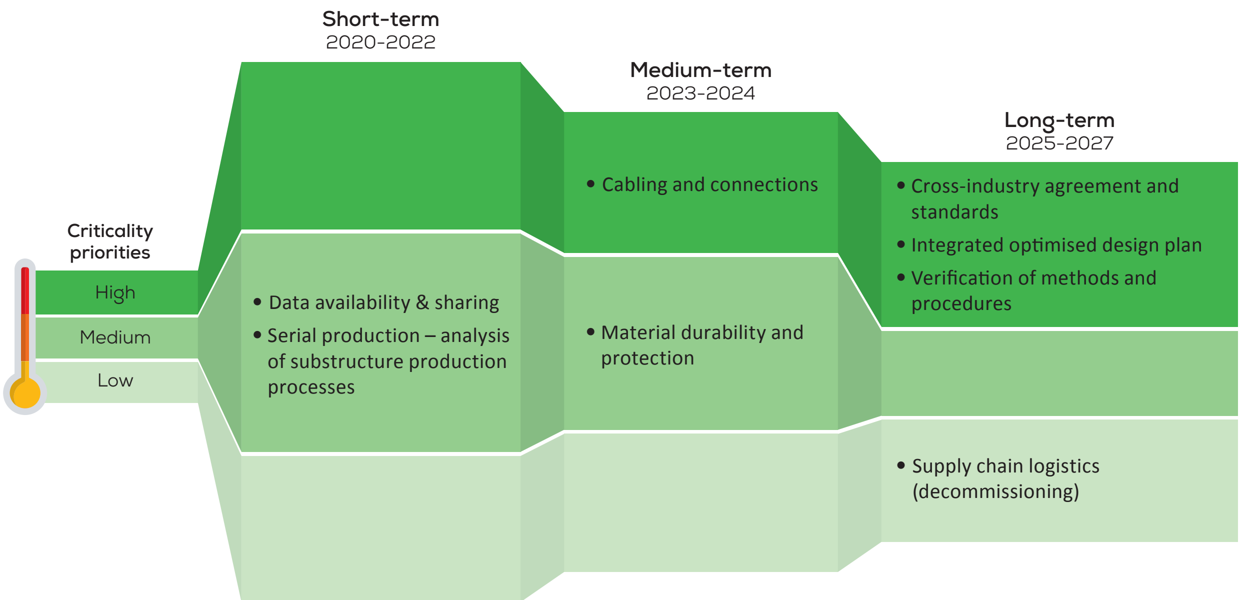
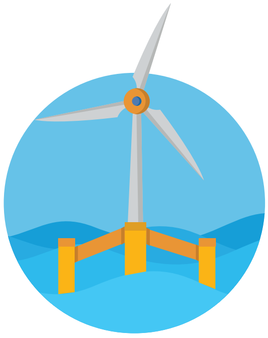


Figure 9 Research & Innovation action areas for offshore balance of plant



Floating offshore wind

Floating offshore wind is a fast-maturing technology with the potential to cement Europe's leadership in renewables globally. European companies are floating pioneers and are leading three quarters of the more than 50 projects worldwide today. However, Asian markets are opening at an increasing pace whilst European plans for floating wind have lost momentum.

Europe still has the possibility to capitalise its first mover advantage. To maximise the local economic benefits of a nascent floating offshore wind supply chain, the EU and the Member States must act immediately as other countries (e.g. Japan, South Korea) are significantly increasing their investments in floating offshore wind.

EU support should ensure that cost reduction continues and that European companies are in a position to break global markets with European technology. To do so, the sector needs economies of scale (volumes), low financing costs and R&I funding.

Challenge 1

Serial production

To make floating offshore wind cost-competitive with other energy sources, large volumes of floaters need to be produced and installed. The characteristics of offshore conditions vary across European waters, meaning there will not be a single "one size fits all" solution. As such the first step to industrialisation is to identify and select the best designs for each environment and market.

R&I is needed to develop deployment models, case studies and market assessments to identify which designs and concepts are marketable under which conditions. Ease of manufacturing, transportation, installation and operation in a variety of markets and environments should be clearly assessed. The priority is to develop the floating design that offers best value for money. A design that performs well and can be easily mass-produced at low costs.

Kick-starting a new supply chain will require detailed planning and harmonisation across many economic sectors. R&I support to increase the manufacturing capacities of the suppliers, upgrade port infrastructure, develop new maritime vessels and design new grid connections support will drive floating wind forward and create significant economic impact too.

Challenge 2

Floating wind farms

Wind and wave interactions cause floating wind turbines to oscillate much more heavily. Whereas bottom-fixed turbines have Eigen periods ~less than 3 sec., floating wind turbines will have natural periods of up to more than 100 sec. Better understanding of the wind and wave interactions at park is essential to optimise the layout of floating wind parks and the design of floating wind turbines. The need for accurate wind resource assessment in deep waters, where meteorological masts are proscribed, is also crucial.

The meandering wake and the wind field coherence inside the park also need to be well defined to optimally design the floating wind turbines. The larger motion of floating turbines creates a design challenge in terms of load fatigue to several components. The most obvious are the rotating components in the nacelle, the tower, blades, power cable and mooring lines. R&I in design models and control methods will alleviate load problems.

As the size of the turbines increases, assembly and heavy maintenance operations become a challenge. Regular jack-up vessels cannot be used for installation and heavy maintenance in a floating wind farm. Innovative solutions and concepts need to be developed to ensure low cost installation and maintenance operations. The installation and hook-up of the mooring system and the dynamic electrical cable is another crucial part of the installation process of floating wind farms.

Monitoring the aging of these components under cycling loads and marine growth can significantly contribute to cost reduction through lifecycle management. In waters deeper than 100m it is difficult to fix the array cables to the seabed. R&I will need to find solutions to overcome these challenges. Public funding and dedicated joint programming initiatives are instrumental to ensure Europe will lead the way in floating offshore wind.

Wider regulatory requirements

Expansion of floating offshore wind will allow Europe to tap into massive offshore resources and secure the technology leadership of European companies on the global market. In addition to supporting development of floating wind technology, large scale deployment of floating offshore wind farms will be paramount. The following recommendations will ensure floating offshore wind becomes a true European success story:

- Member States should set their ambitions for capacity, project pipelines and supporting policies for floating offshore wind in their National Energy and Climate Plans (NECPs) to 2030;
- The European Commission should publish the aggregated European volume of floating offshore wind projects to 2030 to enable a clear market visibility for investors and industry;
- Member States should coordinate their schedules of deployment and supporting policies for floating offshore wind in order to maximise regional cooperation in the development of a European supply chain;
- The EU should earmark funding instruments targeted to provide access to low cost financing for floating offshore wind projects and increase the funding to R&I focused on cost-competitiveness; and
- The EU should dedicate Cohesion Funds to support coastal areas and regions upgrading their infrastructure to facilitate development of floating offshore wind.

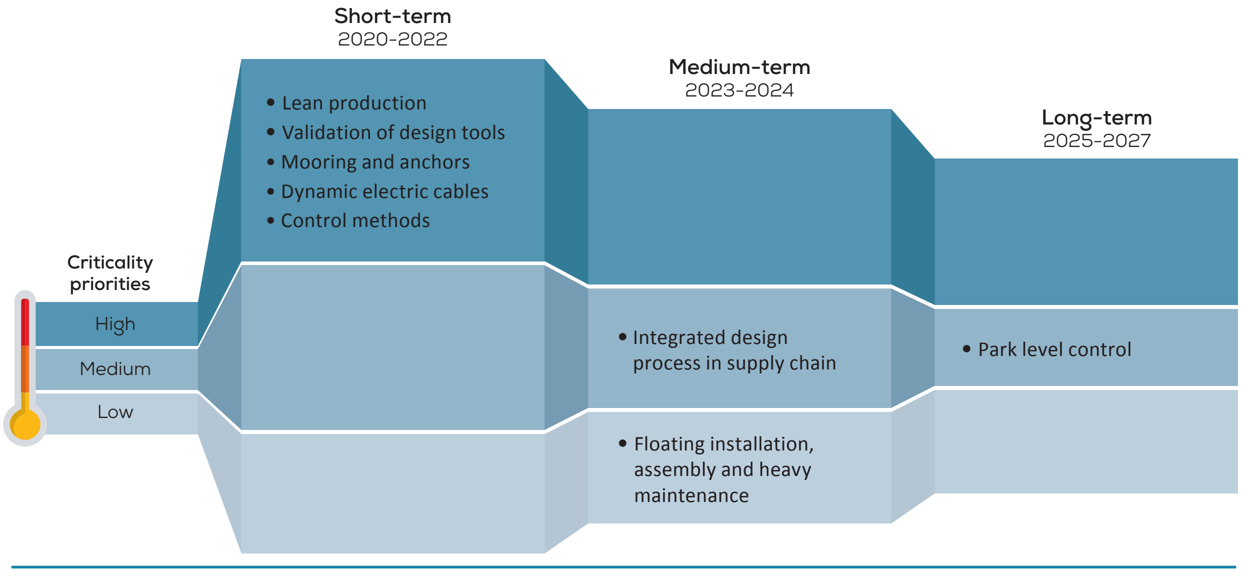


Figure 10 Research & Innovation action areas for floating offshore wind

Skills & human resources

The European wind energy sector is rapidly growing. In just 15 years installed capacity increased more than fivefold, from 34 GW in 2004 to more than 190 GW installed in 2019.[29] At the same time the number of employees quadrupled to over 300,000 in 2019.[30] Job growth in the wind energy sector is driven by two factors. One is a growing market, which sees more turbines being built and installed. The other is the ageing of the existing fleet, as older turbines require more regular and intensive maintenance.

However, the growth of the industry is not supported by an equally stable growth in available skilled labour and excellent scientists. By 2030 there could be a mismatch between demand and supply of up to 15,000 jobs, mostly in operations and maintenance.[31] And more workers are needed; from 2021, annual installations of close to 20 GW (offshore and onshore combined) will be required to reach Europe's ambitious climate and energy targets.

The skills gap is undermining the future of the wind energy sector as companies struggle to fill in the necessary positions. As a result, companies are increasingly targeting their competitors with aggressive headhunting strategies, especially in the operations and maintenance and component manufacturing sectors. For some profiles the needed talent is available outside Europe. This could explain in part why more European companies investment in their non-EU based research and development and manufacturing facilities. Broadening the available European pool of talent could therefore keep significant investments in Europe.

Challenge 1

Ensure a stable pool of skilled and qualified talent

In the short term, industry and educational institutions should come together and map out the required skills on the one hand and the available Vocational Education and Training (VET) qualifications programmes on the other. This skill map should include cross-sectoral dialogues to discover possible synergies and develop joint skills roadmaps. For offshore wind this includes the ocean energy and offshore Oil & Gas sectors. For onshore synergies with regard to the reskilling and retraining of coal workers should be explored.

Whilst certain skills are transversal for the entire energy sector, specific multi-disciplinary profiles such as including project managers, mechanical, electrical and civil engineers, plant operators, logistic experts, and offshore technicians for operations and maintenance are in high demand by the wind energy industry. In addition, the sector will need to fill in new profiles related to commerce, stakeholder management and digitalisation (e.g. big data analysts and robotics experts).

In the long term, more investments are needed to support the wind energy academic community. Professors and researchers are essential to form and educate the next generation of wind energy workers. Today many teaching positions are heavily dependent on erratic funding streams. Multi-annual EU grants can significantly strengthen and stabilise academic research and teaching in wind energy.

Universities and higher education institutes should also develop more sector-specific degrees or an integrated umbrella degree (mechanical, electrical engineering, etc.). Where relevant, this should be in joint efforts with industry players who can pass on manufacturing trends and increase focus on product design and digitalisation. As the wind sector demands a highly mobile workforce, universities should offer more mobility schemes to early-stage researchers and students so that future workers can get accustomed to working in different European regions early on.

Wider regulatory requirements

To ensure Europe remains a global innovation hub for renewable energy, and wind energy in particular, the growing skills gap will need to be addressed with immediate effect. To close the gap we recommend that policymakers:

- Establish EU-wide industrial policies for the energy transition that include funding programmes for re-training and skilling of workers from unsustainable sectors such as coal mining and offshore Oil & Gas;
- Strengthen opportunities for industrial learning experiences, support joint initiatives by industry and higher educational institutes for *in situ* training and skill development programmes;
- Harmonise Vocational Education & Training programmes across Europe so that worker qualifications are more easily recognisable across Europe and worker mobility increases;
- Standardise technical training and Health & Safety (H&S) standards to further improve worker mobility between sectors and across Europe within the same sector; and
- Ensure Science, Technology, Engineering and Maths (STEM) skills of students are of a high standard so that young professionals can enter engineering sectors such as the wind energy sector effortlessly.

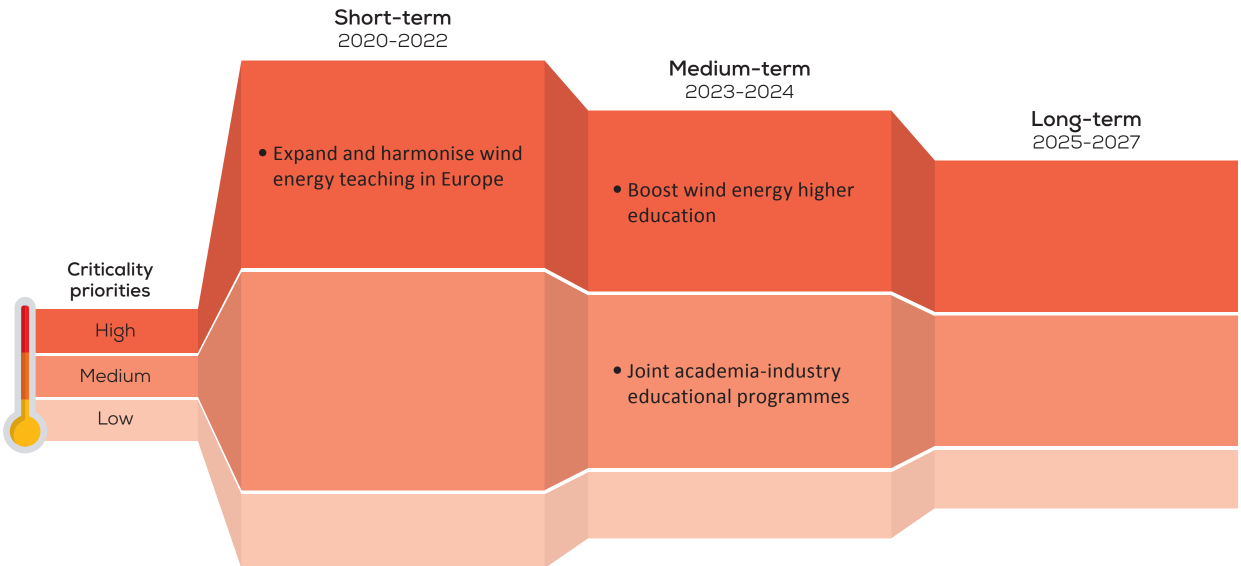


Figure 11 Research & Innovation action areas for skills & human resources

4

The value proposition of wind energy

The EU has pledged to a strong decarbonisation of its economy and this will require a radical energy transition

The EU has pledged to a strong decarbonisation of its economy and this will require a radical energy transition. To do so, all consumers will need to change energy consumption habits, reduce dependency on polluting fossil fuels and make full use of readily available clean renewable energy sources.

However, the energy transition also offers Europe new opportunities to improve environmental conditions, develop new, clean economies and industries, increase energy independence and strengthen global and local competitiveness in renewable energy technology.

The energy transition requires significant investments, but maintaining the existing system comes at a cost too. Estimations are that the investments needed to maintain the status quo are almost equal to those needed for the energy transition.[32] However, the societal cost of the status quo would be significantly higher.[33] This shows that economics and ecology can go hand-in-hand.

In this chapter we will highlight the benefits of wind energy to reduce the environmental impact of the European power sector and at the same time strengthen Europe's industrial footprint.

Improve the health of all Europeans

Fossil fuel and biomass power plants all propel harmful particles in the air and transitioning to clean renewable energy sources will drastically improve air quality. More than 400,000 people die each year in Europe due to air pollution. It is the single largest environmental health risk in Europe.[34,35] Coal power plants alone contribute to more than 22,000 premature deaths each year. In 2013 the total health costs caused by coal power generation could have been up to €62 billion.[36]

Wind energy is a clean, free and abundant resource that can be extracted and converted into electricity without any emissions. Phasing out fossil-fuelled power plants and replacing them with more wind power will be a big help in fighting climate change and as such help to reduce unnecessary health problems, increase lifetime expectancy and avoid billions of health-related costs.

Reduce environmental footprint

Wind and other variable renewable power generators also have the benefit that they do not require water to operate, unlike thermal generation (coal, gas and nuclear). In 2015 the European power sector withdrew 74,000 billion litres of fresh water or close to 42% of all water extraction in Europe that year. Most of the water was surface water extracted from rivers and lakes. Some 3,800 billion litres were consumed and never returned to the waterways.[37]

Prolonged periods of heat and drought put stress on a power system based on thermal generation. Thermal plants require massive amounts of surface water for cooling, so any decrease in the debit of rivers or any increase in the average water temperature has a direct negative effect on their operation. In fact, thermal plants already need to reduce their power output during summer, at moments when demand is typically high.[38,39]

With the expected increase in extreme weather events due to climate change, the reliance on thermal power generation is a direct threat to Europe's energy security. Wind energy has a negligible impact on the water table. So, more wind power will reduce the stress on Europe's water supply, decrease water scarcity and guarantee stable power supply during prolonged moments of extreme heat.

In 2015 the European power sector withdrew

74,000 billion litres of fresh water

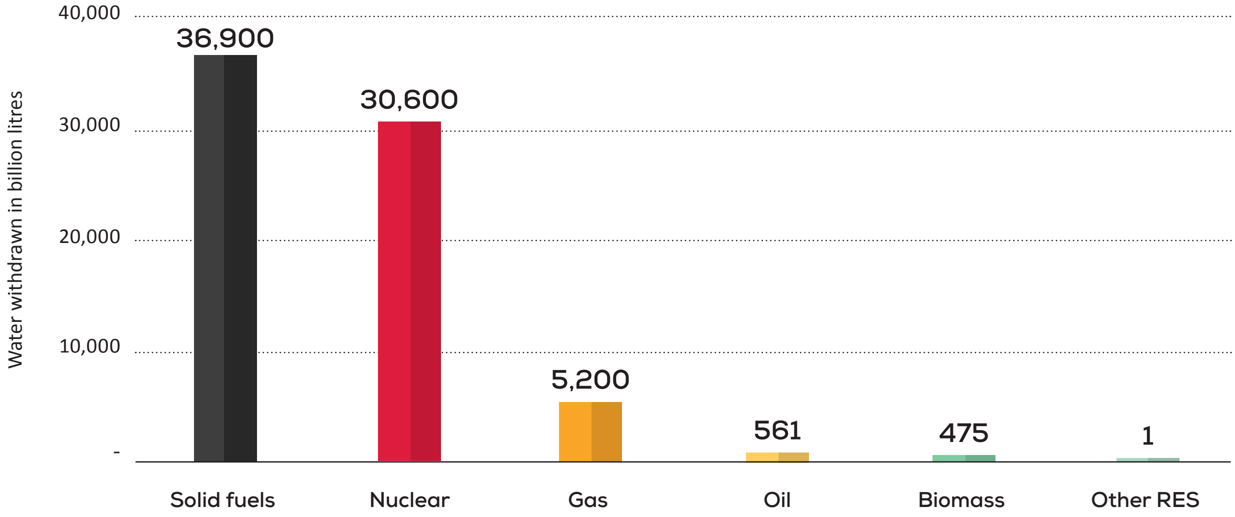


Figure 12 Water withdrawal by the European power sector in 2015

Reduce carbon footprint

As established earlier in this report, a decarbonised power system is essential to reach the Paris Agreement targets. In 2017 the European power sector had a total carbon footprint of more than 1 billion tonnes of CO_2equivalent (CO_2eq) and 97% came from combusting fossil fuels.[40] This carbon footprint does not only include emissions during power production, but rather all the emissions during the lifecycle.

According to the Intergovernmental Panel on Climate Change (IPCC), wind energy has the lowest carbon footprint of all power generation technologies. On average it emits just 11.1 grams of CO_2eq for each kWh produced throughout its lifetime.[41,42] This is more than 4 times less than solar photovoltaics (48g/kWh) and 80 to 100 times less than solid fossil fuels (820-1075g/kWh).[43]

So installing more wind turbines and phasing out fossil-fuelled power plants is the most effective way to abate CO_2 emissions. An accelerated coal phase-out coupled with increased deployment of onshore wind could already see a reduction of 204 million tonnes of CO_2 each year.[44]

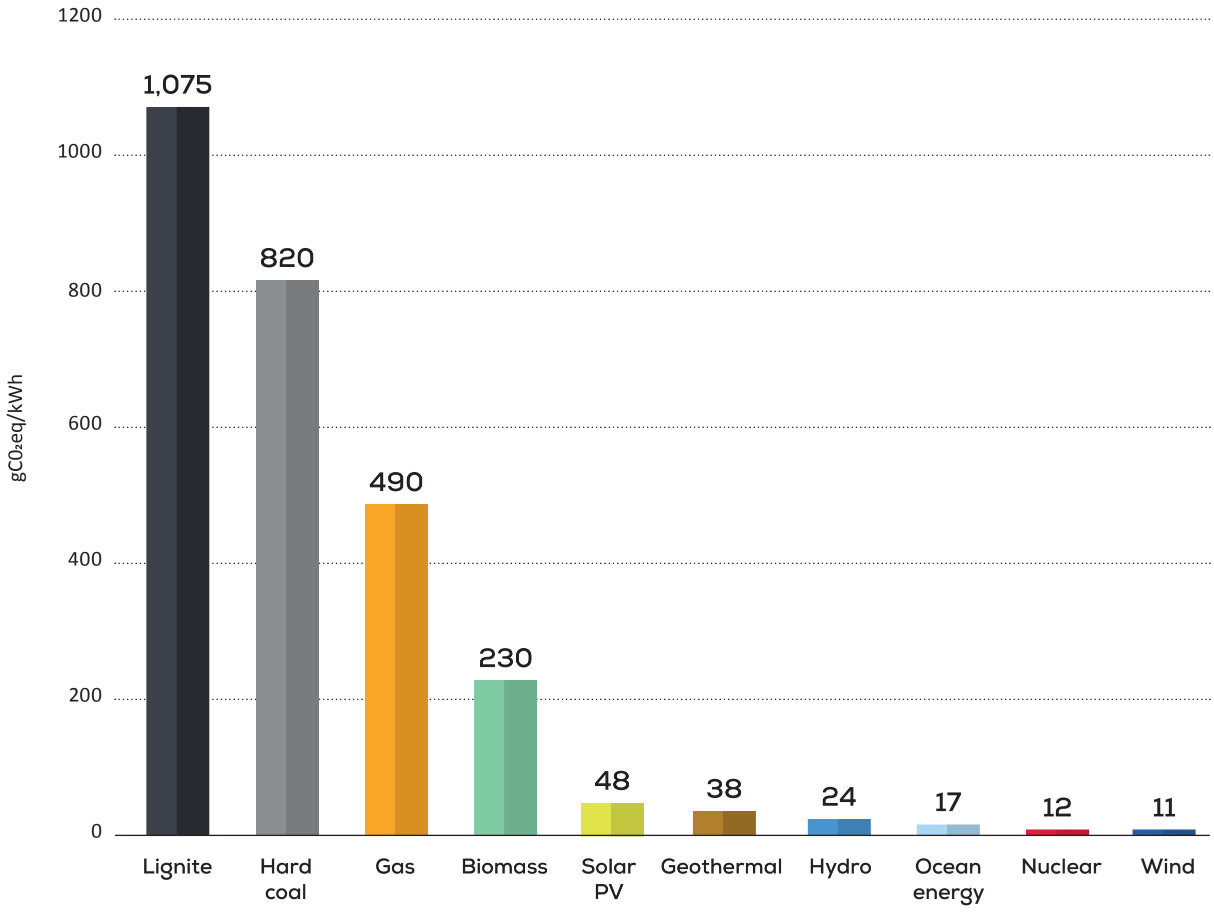


Figure 13 Carbon emissions per energy technology across the lifecycle

Reduce external costs

The wind energy sector has seen massive cost reductions in recent years. Wind power is increasingly competitive vis-à-vis the conventional, polluting energy sources like coal and lignite.[45,46] Strike prices for onshore wind auctions have dropped from over €100/MWh in 2013 to €40/MWh or less in 2017. Onshore wind is now the cheapest source of new installed power capacity in many parts of Europe. Offshore wind is not far behind. In the same period costs fell from over €150/MWh to €65/MWh.[47]

However, the auction strike prices and Levelised Cost of Energy (LCOE) do not tell the whole story. Every economic activity also has external costs. These costs (called externalities) account for the wider environmental and societal impact and they have been researched since the 1980s.[48] For the power sector, these costs are mostly comprised of costs of emissions and land use. According to the IPCC wind has the lowest external cost. The external cost of solid fuels are at least 50 times higher and even other renewables such as solar photovoltaics and biomass bring significantly more external costs.[49]

From the external cost values calculated by the IPCC we can estimate that the total external cost of the European power sector in 2017 amounted to €86.9 billion.[50] Fossil-fuelled power generation accounted for 88% of that, a staggering €77 billion. Decarbonising the power system would thus not only help reduce carbon emissions, but also reduce the external cost of the power sector.

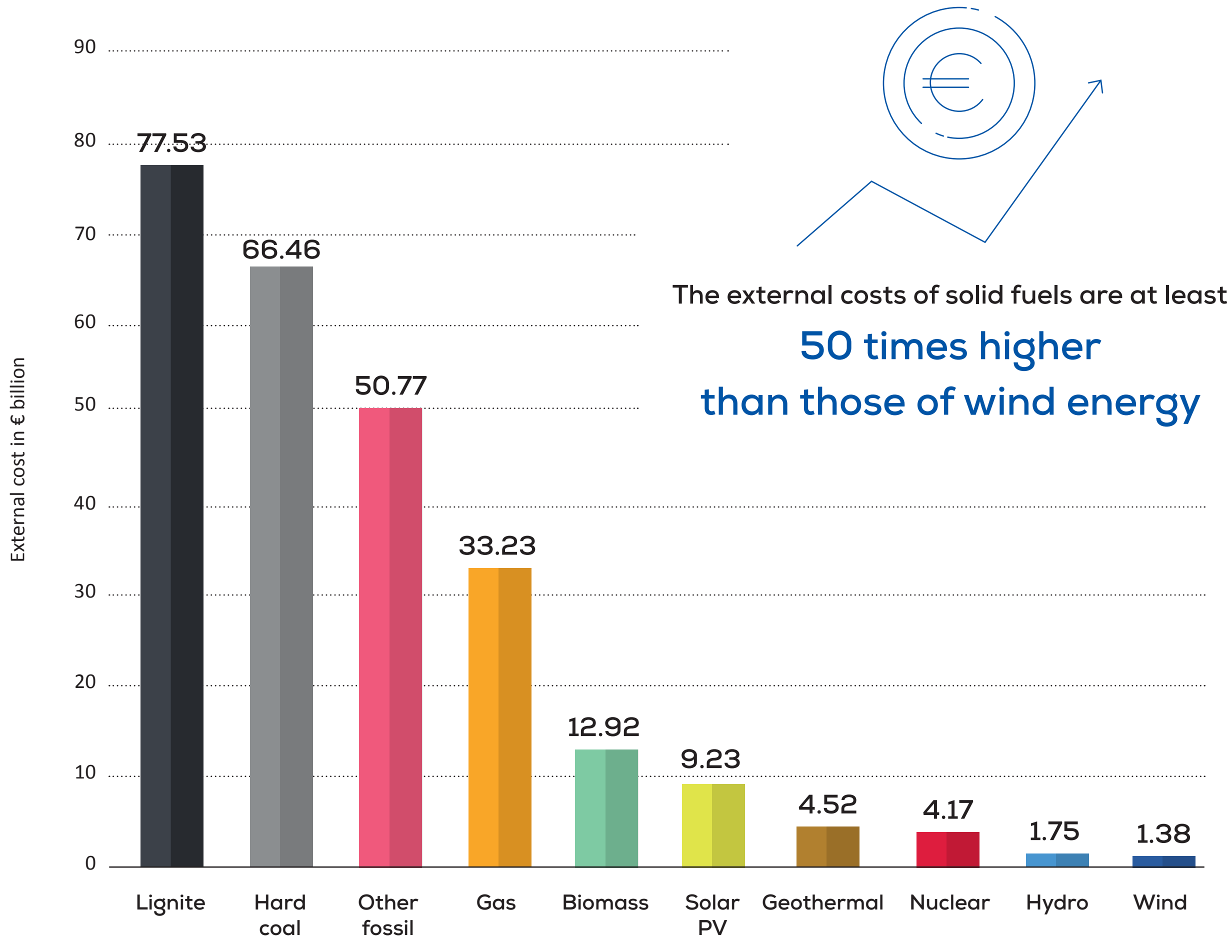


Figure 14 External cost of power generation technologies

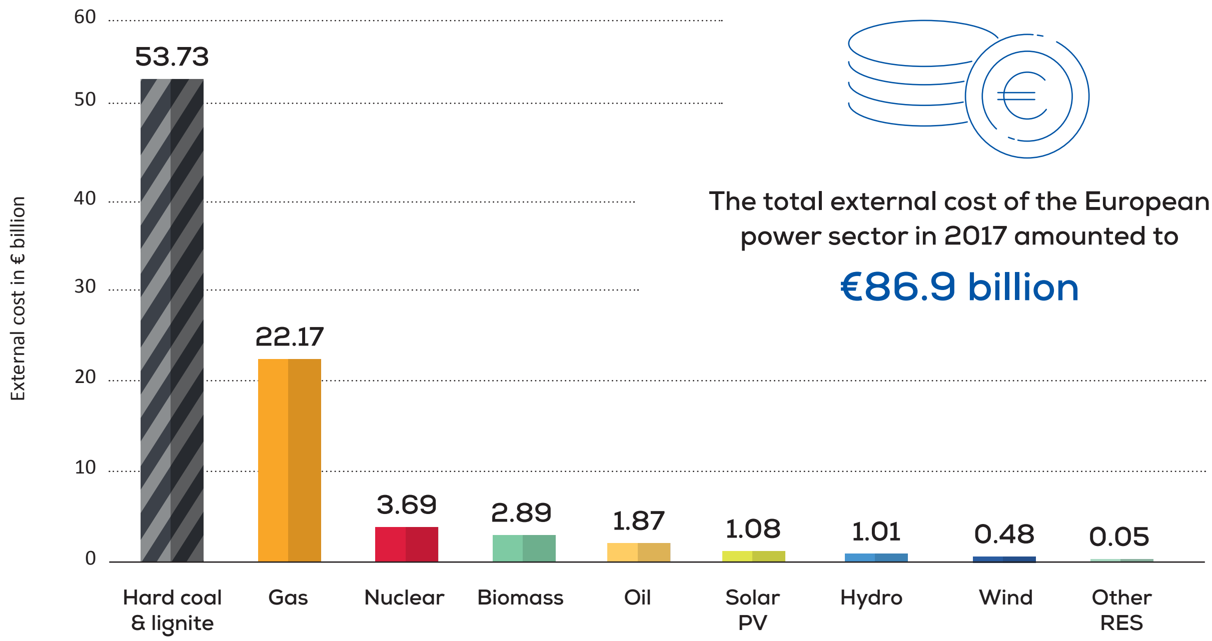


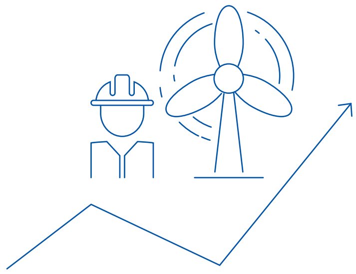
Figure 15 External costs of the European electricity system in 2017

Provide thousands of green jobs

Investing in the energy transition will increase employment. The International Labour Organisation (ILO) estimates that investments in line with limiting global warming to 2° Celsius will bring a net increase of 2.1 million jobs in renewable electricity alone at a global level.[51] Many of those new jobs will be in the wind sector.

Thanks to the success of European wind turbine manufacturers and ambitious European climate and energy policies, Europe is the cradle of wind energy technology. More than 15 countries have established wind energy research centres. At the same time the wind energy sector has become an integral part of the European industrial fabric and provides jobs to many thousands of people all across Europe.

In the last 15 years employment in the wind energy sector has quadrupled. In 2004 the wind sector provided for 72,275 jobs.[52] In 2019 this is already more than 300,000, equal to two thirds of the coal sector today.[53,54] Wind energy is also one of the most labour-intensive sectors. Every GWh produced supports almost 1 full-time job.[55]



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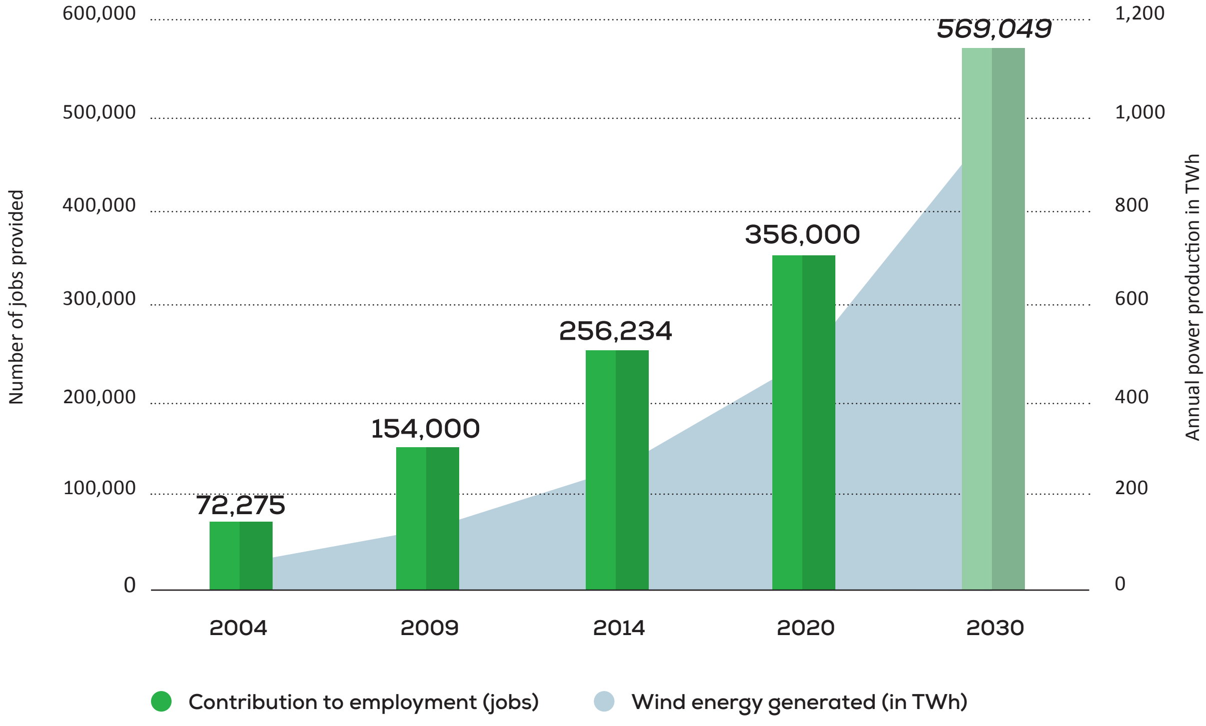

Figure 16 Projected employment in the European wind energy sector

5
Annexes

Annex 1 **Methodology**

Energy system

WindEurope's projected evolution of the European energy system and the growth of the wind energy sector is based on data provided to WindEurope by DNV GL. This data builds on the 2018 edition of the annual DNV GL *Energy Transition Outlook* and has also been used for the 2018 WindEurope publication *Breaking new ground*. The assumptions for the analysis and scenarios are explained in the *Breaking new ground* report.

To retain methodological consistency throughout the report, we have also used DNV GL data for the 2017 baseline, even if EUROSTAT data for that year was already available. We did note only minor discrepancies between the data reported by EUROSTAT and DNV GL.

Carbon footprint

To calculate the carbon footprint of the electricity system, we have used the life-cycle carbon emissions of every power generation technology as calculated by the Intergovernmental Panel on Climate Change (IPCC). These values are shown in figure 13.

As the IPCC did not distinguish between hard coal and lignite, we calculated an average carbon emission value for lignite based on data from a German study form 2007.[56]

The estimated total carbon footprint of the European electricity system in 2017 was obtained by matching the IPCC's carbon footprint value of each technology's with Europe's gross electricity production for 2017. For this calculation we have used the data provided by DNV GL.

External costs

To calculate the external costs of the European electricity system, we have used the external cost values as calculated by the IPCC. These values are shown in figure 14.

We note that there has been extensive research into calculating external costs or externalities, but no single methodology is used. As a result, external cots values can vary greatly from study to study.

Even if the values defined by the IPCC are global values and at times rather conservative compared to the findings of other studies (especially with relation to gas and nuclear), they are an internationally recognised benchmark.

The estimated total external cost of the European electricity system in 2017 was obtained by matching the IPCC's external cost value of each technology with Europe's gross electricity production for 2017. The result is shown in figure 15.

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