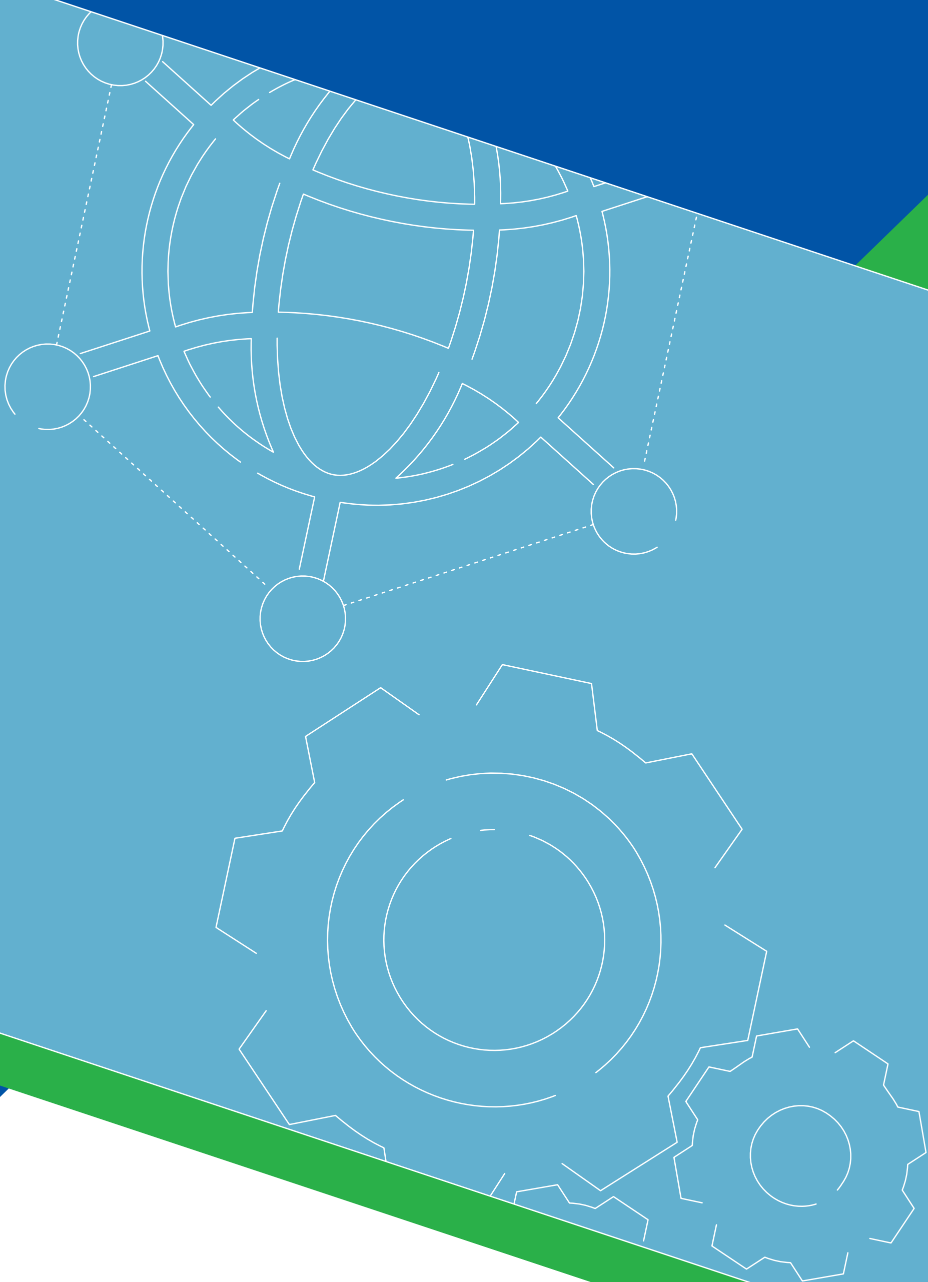

ETIPWind Roadmap

Next generation technologies

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

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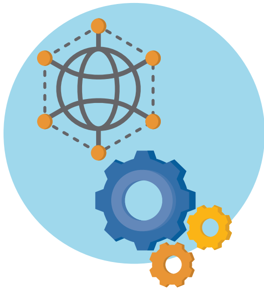

Next generation technologies

Today wind energy is the cheapest source of new installed power capacity in many regions of Europe. 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 rapidly drive down costs for wind energy, 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 Europe's industrial fabric. It is 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 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 to 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.

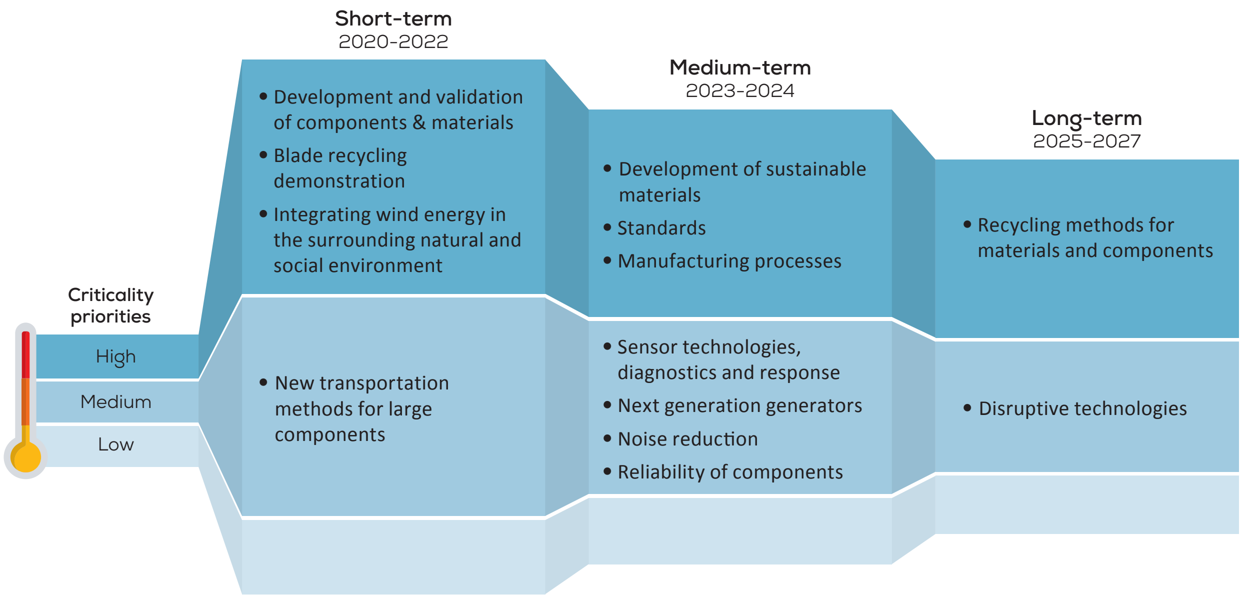

Figure 1 Research & Innovation action areas for next generation technologies

Challenge 1.1

Cost competitiveness of the EU wind industry

Development and validation of new components & materials	Short-term	High priority

Description and scope

With the foreseen size of future wind turbines, thorough testing and validation of new materials and components will be key. Numerical methods for digital twins will play an important part, too. As in every industry, the search for new components and materials is a continuous task.

Strengthening resins or reinforcing fibers with nanoparticles could improve the mechanical characteristics of ever longer and more slender rotor blades. New artificial materials, could replace balsa wood in rotor blades, natural materials like wood might replace materials like concrete or steel in other components. The objectives are to further reduce the Levelised Cost of Energy (LCoE), CO_2 footprint as well as improving the physical properties of the wind turbine.

Recommended research actions

- Determination of the most effective (nano-) reinforcement method specific to e.g. plydrop zones, considering the aspects of ease of application and improvement in the structural properties assessed through mechanical testing.
- Investigate and evaluate a method for cost and material effective connections between components of different materials (e.g. wood, steel, concrete), including material testing and strength analyses of adjacent joints.
- Developing, testing and implementing solutions for preventing unwanted effects, like surface charging, when introducing new materials.
- Provide a set of benchmark experiments for fatigue-driven problems at component or subcomponent level.
- Validation of simulation methods using benchmark experiments.

Milestones

- Demonstration of enhancement in the structural integrity of composite blades through nano-particle reinforcement.
- Test methods for effective connections between natural and artificial materials are validated (e.g. wood and concrete).
- Clear benchmarks (experiment and simulation) for new coating materials are developed.

Challenge 1.2

Cost competitiveness of the EU wind industry

New transportation methods for large components	Short-term	Medium priority

Description and scope

The increasing globalisation of the wind energy sector increases the challenge to rapidly source high quality materials and components needed for wind turbine installations. Combined with the market's push to continue developing bigger wind turbines, this creates a constant pressure on the transportability of wind turbine components.

New transportation methods (e.g. cargo airships) for large and heavy components will increase transportability, limit the impact of wind energy installations on mobility flows, reduce carbon emissions and help to reduce Levelised Cost of Energy (LCoE). They could also open up new sites for wind energy development that are inaccessible with current transportation methods.

Recommended research actions

- Concept development
- Future blade transportation requirements to be mapped (geography, cost, geometry).
- Cargo airship to be further developed and financial/environmental benefits documented.
- A cargo airship scale demonstration is needed to mature and validate:
  - Certification and flight operation legislation for cargo airships for wind power.
  - Technical evaluations and feasibility study.
  - Define conceptual deployment plans for cargo airships for wind power.

Milestones

- Cost-benefit analysis of possible transportation methods.
- Establishing a new regulatory framework for heavy freight transportation.
- Test flight of cargo airships.

Challenge 1.3

Cost competitiveness of the EU wind industry

Standards	Medium-term	High priority

Description and scope

The wind industry is a relatively young industry compared to other industries, and it has developed rapidly over the last decade. However, this development has not been a concerted industry effort like for other heavy industries like the car and aviation industry. Many of the design solutions are highly specialised and unique and this drives up individual manufacturing cost.

In effect, the highly technical wind energy industry currently lacks standards and harmonised best practices. Furthermore, the design standards currently used - International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO) and the American Composites Manufacturers Association (ACMA) - were not necessarily developed for the wind industry. Therefore, the technology developed is in some cases over engineered in order to be compliant with the standards. A series of standards has been made under the IEC 61400 but that work has just started.

Increased standardisation in design will help increase production volumes, lay the foundation for technology leaps through shared research, increase quality and simplify design, documentation and verification processes.

Harmonisation of regulations across EU countries will support standardisation initiatives in Europe and help Europe in setting the trend for how to design wind turbines in the rest of the world.

Recommended research actions

- Review current standards and create a roadmap for new standards like IEC, ISO to support future optimisation of turbine design.
- Explore the opportunities in the use of digital twins in the verification of various turbine components.
- Map the use of components that are regulated differently in different EU countries and standardise them to drive cost down (e.g. aviation lights, safety system, fire extinguish systems).
- Develop a standard transportation tools for heavy equipment and harmonise regulations across the EU.

Milestones

- European roadmap of standardisation opportunities on turbine level, component level and logistics (transportation).

Challenge 1.4

Cost competitiveness of the EU wind industry

Manufacturing processes	Medium-term	High priority

Description and scope

The growth in wind turbine size and hub height is challenging existing manufacturing methods. New manufacturing methods, processes and facilities will be needed to ensure wind turbine manufacturers can continue to produce the wind turbines that the market demands in Europe.

Europe's manufacturing base is challenged by the introduction of local content requirements in many non-EU countries, increased variety of regulations and increasing customer demands for the traceability of materials. The consequence for the European industry is a higher manufacturing cost for turbines made in Europe and an increased CO_2 footprint of manufacturing processes globally.

An increased effort is needed in research of the use of digitalisation to manage the processes and the use of robots to bring down manufacturing costs and to cope with turbine growth.

Increased research on manufacturing mobility is relevant, not only for cost reduction but also to find other ways to reduce the CO_2 footprint.

Recommended research actions

- Develop robot technology to cope with turbine growth and to reduce manual work in e.g. blade production.
- Develop further the area of utilising smart supply network with the primary goal of reducing CO_2 footprint.
- Develop the next generation of sensor technologies to support real-time mapping and traceability of materials in the manufacturing process.
- Develop further tools and processes for 3D printing of large components.
- Further develop cyber security in mobile manufacturing.
- Further develop artificial intelligence to optimise manufacturing processes.

Milestones

- Supplier's register for material and component traceability.
- Demonstration of new high precision manufacturing lines for wind turbine components.

Challenge 1.5

Cost competitiveness of the EU wind industry

Sensor technologies, diagnostics and response	Medium-term	Medium priority

Description and scope

The use of new or better integration and combination of already existing sensors (e.g. lidars) will enable wind turbines and wind farms to use smarter and more powerful controllers, which will also contribute to the development of diagnostic systems. The 'rotor as a sensor' and 'smart blade' developments are promising solutions for future wind turbines can better operate in unsteady wind conditions (turbulence, wakes, shears etc.).

This development will increase the number of signals and data significantly and therefore sophisticated numerical tools (e.g. analytical methods and tailored artificial intelligences) have to be developed. All of this will reduce safety margins and black-box approaches, due to better insights in e.g. aerodynamics and aeroelasticity.

Recommended research actions

- Development of smart rotor technologies, including necessary sensors and controllers.
- Development of (big) data acquisition, storage and analysis methods based on machine learning and physical modelling.
- Setting up of demonstration and testing facilities to try out new condition monitoring techniques (test rigs, test turbines, test wind farms).
- Study of uncertainties and errors in measuring chains.
- Improving structural health monitoring by embedding methods and sensor data in digital twins on turbine and wind farm level.

Milestones

- Condition monitoring systems which combine traditional SCADA, condition monitoring systems, higher frequency measurements, physical modelling, machine learning and prognostics to provide a step change in turbine operations & maintenance (O&M).
- Standards and harmonisation for data acquisition and data analysis.
- Reduced operations & maintenance cost by 10-15% by 2025.

Challenge 1.6

Cost competitiveness of the EU wind industry

Reliability of components	Medium-term	Medium priority

Description and scope

Turbine growth in rotor diameter and hub height makes modern wind turbines more sensitive to aeroelastic instabilities both in operation and in standstill conditions. To fully understand the impact of those conditions and find effective and actual solutions, their effect on components with unavoidable imperfections has to be analysed and tested.

Probabilistic design methods with known statistical scatter of the material properties could support reducing risks and uncertainties. Deep learning technologies combined with numerical simulations can support the detection of failure mechanisms in all components, electrical and mechanical.

Recommended research actions

- Reliability modelling with uncertainty consideration and taking into account failure mechanisms.
- Development of digital twins of key components and systems.
- Maturing of computational-fluid-dynamics-based aeroelastic analysis methods, backed by dedicated wind tunnel or full-scale tests.
- Measuring of reliability-relevant imperfections.
- Determination of model uncertainties.
- Development of a virtual simulation environment for the economic quantification of material uncertainties.

Milestones

- Model uncertainties based on component test.
- Probabilistic modelling as a standard.
- Reduced spare parts inventory.

Challenge 1.7

Cost competitiveness of the EU wind industry

Next generation generators	Medium-term	Medium priority

Description and scope

Wind turbine generators are approaching physical limits as wind turbines are growing larger. New materials (e.g superconducting material, rare-earth-free magnets) and new topologies are possible solutions. Electromagnetic coupled mechanical dynamics under complex operation conductions have to be handled to develop low cost, highly reliable future drive trains.

For modular generators faulty modules can be turned off and the turbine can continue to generate power, while repair logistics become easier and take less time.

For floating wind new concepts are needed as until now, onshore rotors are just slightly modified (controller) in adaption to floating conditions. A high fidelity multidisciplinary integrated tool could help to improve this via the entire Technology Readiness Level (TRL) range.

Recommended research actions

- Developing new materials and generator topologies.
- Researching electromagnetic coupled mechanical dynamics in wind turbine drive trains.
- Research the most suitable generator topologies for modularity.
- Determine the generator faults with the highest frequency rate.
- Research the suitable electric drive topologies for modular generators.
- Investigation of generator driver control techniques under lighter loads to maximise efficiency.
- Investigation of generator driver control techniques under faults to continue operation.

Milestones

- Validated prototypes of modular generator systems.
- Suitable generator topologies and materials for next generation generator, validated through simulation and experiments.

Challenge 1.8

Cost competitiveness of the EU wind industry

Disruptive technologies	Long-term	Medium priority

Description and scope

The trend of lower specific power rotors could open up new markets to European manufactures and support grid stabilisation. Smart passive and active control methods, aeroelastic tailoring can help in keeping capital expenditures (CAPEX) low for those turbines.

Developments in electrical components, like high-voltage generators or super-conducting generators have disruptive potential, too. Possible large reductions in the weight of transformers could have a positive impact on offshore installations and Levelised Cost of Energy (LCOE).

Concepts like floating vertical axis wind turbines (VAWTs), airborne wind or multi-rotor turbines can also open new markets or applications. Also, multi-usage systems (energy/energy or energy/non-energy combinations) can reduce system costs.

Recommended research actions

- Conceptual design of low wind rotors aiming at light-weight low CAPEX designs.
- Application of smart blade approaches (passive load reduction) and disruptive non-conventional rotor designs (downwind-free yaw/folding blades) for reduced operational and extreme loads.
- Design of high voltage generators without permanent magnets.
- Design of Direct Current/Direct Current (DC/DC) converter with high frequency transformers.
- Development of multi-unit concepts.
- Identifying markets and applications as well as feasible concepts for vertical axis, airborne and/or multi-rotor wind energy systems.

Milestones

- Conceptual design of a disruptive low specific power wind turbine.
- Smart blades/rotorss in commercial projects.
- High voltage generator without permanent magnets in MW-size.
- Deployment of DC/DC converters in wind farms.

Challenge 2.1

Towards a 100% sustainable wind energy sector

Integrating wind energy in the surrounding natural and social environment	Short-term	High priority

Description and scope

Specific technical actions are needed to help ensure bigger turbines retain a low environmental impact. On the other hand, social actions are needed to improve popular acceptance towards and happy co-existence with wind energy projects. The development of the acceptance of on- and offshore wind turbines and wind farms needs to be investigated in an interdisciplinary context. A particular focus point should be which physical effects created a negative perception of wind energy and how these interact with each other. Technical innovations and new measurement concepts should help to improve the acceptance by reducing visual impact and noise propagation.

Recommended research actions

- Assessment of reliable simulation models for different sources of environmental impact, e.g. noise, vibrations to the soil, visual impact.
- Development of improved design solutions for noise, vibrations, and/or visual impact reduction.
- Creation of projects and campaigns to increase the culture and enhance the positive attitude of people toward wind energy.
- Investigating if small wind turbines in populated/built areas could increase acceptance.
- Long-term change of emissions and acceptance during lifetime.

Milestones

- Development of objective criteria.
- Technical solutions for reduced emissions.

Challenge 2.2

Towards a 100% sustainable wind energy sector

Blade recycling (demonstration)

Short-term

High priority

Description and scope

The volume of blades produced and delivered to the market has increased over recent years due to the exponential growth of the wind energy sector. Many turbines will soon reach the end of their operational life and will have to be decommissioned. While there are good ways of recycling many of the metal parts of a wind turbine, there is still no industrialised method to recycle wind turbine blades as they have a complex material structure (resins, composites, etc.).

Hence, blades at the end of their designed lifetime often end up as landfill or incineration, which is a sub-optimal use of precious resources and materials. A large-scale demonstration of recycling of wind turbine blades, including business cases for the industrialisation thereof, will improve wind turbine circularity, offer new opportunities for the re-use of materials by other sectors and provide the wind energy sector and other composite-heavy sectors with ready solutions to manage upcoming volumes of composite waste.

Recommended research actions

- Development of financial model for recycling of wind turbine blades.
- Assessment of different methods of recycling of wind turbine blades according to developed financial model.
- Demonstration of industrialised recycling of wind turbine blades scalable to the coming volumes of end-of-life blades.
- Demonstration of re-use of materials from recycled blades.

Milestones

- Industrial scale demonstration facility of composite waste recycling dedicated to wind turbine blades by 2022.
- Cross-sectoral pilot project on the re-use of recycled composite materials from wind turbines by 2024.

Challenge 2.3

Towards a 100% sustainable wind energy sector

Development of sustainable materials	Medium-term	High priority

Description and scope

Wind turbine blades are composed out of many materials, but the majority of them are fibre reinforced plastics (FRP). Currently glass fibres are the most used reinforcement fibres, but carbon fibres have already been introduced for longer blades to reduce weight.

Most, if not all, the resins used are thermoset type resins such as polyester, vinylester or epoxy. Recycling of FRP from past and current state of the art wind turbine blades is difficult due to the chemical bonds of the fibers with the plastic and resins.

New sustainable materials fit for use in blades for wind turbines must be developed. The development of these new sustainable materials must be performed in a circular economy framework, securing future wind turbine blades which are sustainable in relation to the economy and resources.

Recommended research actions

- Mapping and evaluation of sustainable material system potential suitable for use in manufacture of wind turbine blades.
- Development of new high-performance materials matching or outperforming current state of the art materials for wind turbine blades and securing full sustainable and easily recyclable blades at end of life.
- Demonstration of the new developed materials in sustainable design of wind turbine blades.

Milestones

- Mapping and evaluation of sustainable material system potential suitable for use in manufacture of wind turbine blades completed.
- Development of new high-performance materials matching or outperforming current state of the art materials for wind turbine blades completed.
- Demonstration of new developed materials in sustainable design of wind turbine blades.

Challenge 2.4

Towards a 100% sustainable wind energy sector

Noise reduction	Medium-term	Medium priority

Description and scope

To improve the social value of wind turbines, noise production should be reduced through dedicated design. On turbine level, improvements in noise-based siting should be achieved. Aeroacoustic noise must be evaluated and integrated in the design loop. Accurate engineering models should be developed and validated with respect to experiments and sophisticated models.

For large wind farms, effects of noise propagation due to atmospheric boundary layer and uneven ground surface become relevant. Mitigation of wind turbine noise can be achieved by further improving passive noise reduction technologies, by understanding and mitigating the detrimental effects due to 3D flow on the noise reduction concepts, and by further reducing secondary noise sources.

Recommended research actions

- Assessment of more reliable simulation models for noise.
- Development of improved design solutions for noise reduction.
- Development of noise-based siting strategies.
- Improvement and validation of the numerical tools from lab experiments and tests on the fields.
- Integration of these models into the design loop.
- Investigate fluid structure interaction and impact on dynamic stall and low frequency noise in and out of rated regimes.
- Development of passive treatments to further reduce noise.
- Long range acoustic propagation (farm level) including atmospheric and ground effects.

Milestones

- Trailing edge noise reduction at full-rotor level and identification of 3D flow detrimental effects.
- Improvement of current trailing edge noise reduction technologies.
- Identification of additional flow-induced noise sources at rotor level (stall noise, tip noise, etc.).

Challenge 2.5

Towards a 100% sustainable wind energy sector

Recycling methods for materials and components	Long-term	High priority

Description and scope

Multiple methods for the recycling of fibre reinforced plastics (FRP) have been investigated. However, only a few have a high Technology Readiness Level (TRL) and have been demonstrated at commercial scale (pyrolysis and cement kiln). Full financial assessment of different methods of recycling of wind turbine blades is needed to find an optimal solution for future volumes of end-of-life blades. Further market barriers for commercialisation of recycling of wind turbine blades/ FRP have to be identified and eliminated to turn recycling of wind turbine blades into a profitable business to the benefit of society and the environment.

Recommended research actions

- Assessment of different recycling methods in a commercial and industrialised framework.
- Identify market barriers for comercialisation of recycling of wind turbine blades and generate recommendations to eliminate those.

Milestones

- Assessment of different recycling methods in a commercial and industrialised framework completed.
- Market barriers for commercialised recycling of wind turbine blades identified.
- Recommendation to eliminate market barriers defined.

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