EERA DeepWind'2020
17th Deep Sea Offshore Wind R&D Conference,
Trondheim, 15 - 17 January 2020

EERA
European Energy Research Alliance
JP WIND

BRINGING OFFSHORE WIND FORWARD THROUGH R&I

Peter Eecen
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R&D Manager TNO Wind Energy

TNO innovation for life

EERA – EUROPEAN ENERGY RESEARCH ALLIANCE

- The European Energy Research Alliance (EERA) is an association of European public research centers and universities active in low-carbon energy research. Wind Energy is one of 15 Joint Programmes.

250+ organisations

50,000+ researchers

30 countries

- Advanced Materials and Processes for Energy Application (AMPEA)
- Bioenergy
- Carbon Capture and Storage
- Concentrated Solar Power (CSP)
- Economic, Environmental and Social Impacts (JP e3s)
- Energy Efficiency in Industrial Processes
- Energy Storage
- Energy Systems Integration
- Fuel Cells and Hydrogen
- Geothermal
- Hydropower
- Nuclear Materials
- Ocean Energy
- Photovoltaic Solar Energy
- Shale Gas (discontinued)
- Smart Cities
- Smart Grids
- Wind Energy

EERA – Joint Programme on Wind Energy

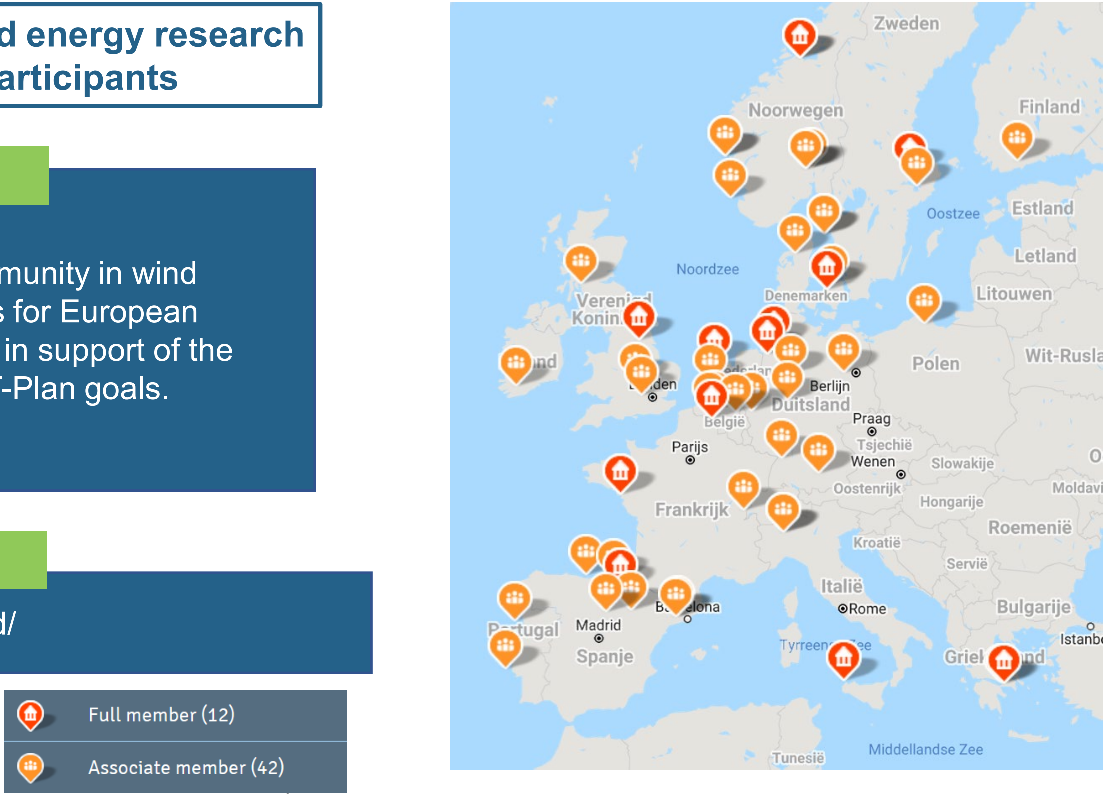
10 years of coordination of wind energy research growing from 13 to 54 participants

Vision

To be the globally leading R&D community in wind energy creating synergy advantages for European research organisations and industry in support of the green energy transition and the SET-Plan goals.

www.eerajpwind.eu

- www.linkedin.com/in/eera-jp-wind/



EERA Joint Programme Wind

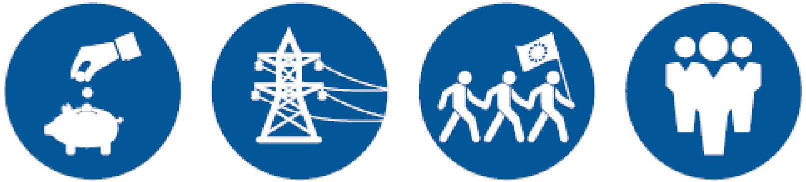
”I want Europe’s Energy Union to become the world number one in renewable energies.”
Jean-Claude Juncker, President of the European Commission

Mission

Build and maintain a world-class wind energy research and innovation community in Europe through increased alignment and coordination of national and European efforts in support of the industry of today and to enable the industry of tomorrow.

JP Wind provides

- Strategic leadership of the underpinning research TRL 1-5
- Joint prioritisation of research task and infrastructure
- Alignment of large European research efforts
- Coordination with industry; and
- Sharing of knowledge and infrastructure
- Mobility and community building



Reduce costs | Facilitate system integration | Reinforce European technological leadership | Ensure first-class human resources

EERA JP Wind

Vision

To be the globally leading R&D community in wind energy creating synergy advantages for European research organisations and industry in support of the green energy transition and the SET-Plan goals.

Key values for participants

- **Be part of the strategic leadership for wind R&D**
  - Contribute to development of and having a voice in R&D and funding priorities, EU and national
  - dialogue with industry and ETIPWind
  - Access to marketplace for shaping EU proposals

Key values for participants

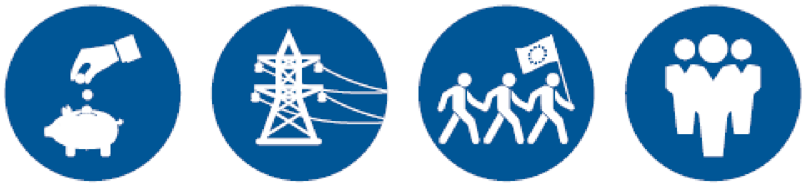
- **Be part of the network of leading R&D groups**
  - Visibility in and access to research area
  - Knowledge sharing and exchange; collaboration across projects
  - Joint use of research facilities and data
  - Mobility, training, dissemination and communication

EERA JP Wind – collaborations and interactions

Key interaction with industry

>> Collaboration and interaction with **industry platform ETIPWind**

- EERA Management Board has 7 seats in ETIPWind and contributes to the ETIPWind meetings and strategy. One seat is reserved for EAWE.



Reduce costs

Facilitate system integration

Reinforce European technological leadership

Ensure first-class human resources

Key interaction with SETPlan and EAWE

>> Collaboration and interaction with **country representatives through SETPlan**

- The SETPlan Implementation plan offshore wind is determined by country representatives coordinated from the SETPlan. EERA JP Wind contributes to the SETPlan Steering Committee by means of the SETWind project. (see Wednesday session)

>> Collaboration and interaction with **European Academy of Wind Energy EAWE**

- Contribution and sessions at the WESC, large overlap in EERA JP Wind and EAWE partners

EERA JP Wind *R&I strategy* 2019

Research Agenda topics:

1) Next generation wind turbine technologies and disruptive concepts
2) Grid integration and energy systems
3) Sustainability, Social Acceptance, Economics and Human Resources
4) Offshore wind (bottom-fixed and floating)
5) Operation and maintenance
6) Fundamental Wind Energy Science

R&I priorities – process

- The Management Board of EERA JP Wind delivered **end 2017** a strategy for EERA JP Wind.
- At the same time, the R&I priorities were defined and delivered. These were used for:
  - Input to EU requests
  - Input to ETIPWind
  - Input and basis for SETPlan Implementation plan offshore wind

- In 2019 EERA JP Wind decided to update, refine and publish the R&I strategy
  - EU is requesting guidance on R&D priorities from different organisations (a.o. EERA).
  - EERA JP Wind aims to support EU by setting the R&I priorities for wind energy.
  - Assist the development of the H2020 programme and refinement of the HorizonEurope calls

EERA European Energy Research Alliance JP WIND

The EERA JPWind R&I strategy – connections

eawe
european academy of wind energy

- ETIPWIND R&I agenda

EERA R&I strategy 2019 – topics

Six urgent and important **topics** have been identified:

1. **Next generation wind turbine technology & disruptive concepts**
2. **Grid integration and energy systems**
3. **Sustainability, social acceptance and human resources**
4. **Offshore wind (bottom fixed + floating)**
5. **Operation and maintenance**
6. **Fundamental wind energy science**

For each topic EERA JP Wind has defined

- priority topics
- Challenges
- key action areas.

R&I priorities – connection to other agenda’s

ETIPWind 2017	ETIPWind 2019	EERA 2017 strategy	EERA 2019 strategy
Next generation technology	Next generation technologies	Next generation technology	**Next generation wind turbine technology & disruptive concepts**
Grid systems, integration and infrastructure	Grid & system integration	Grid systems, integration and infrastructure	**Grid integration and energy systems**
Offshore balance of plants	Offshore balance of plants	Offshore balance of plants	**Offshore wind (bottom fixed + floating)**
Operation and maintenance	Operation and maintenance	Operation and maintenance	**Operation and maintenance**
From R&I to deployment	Digitalisation, electrification, industrialisation and human resources	From R&I to deployment	**Sustainablity, social acceptance, economics and human resources**
Industrialisation	Floating Wind	Industrialisation	
		Basic wind energy science	**Fundamental wind energy science**

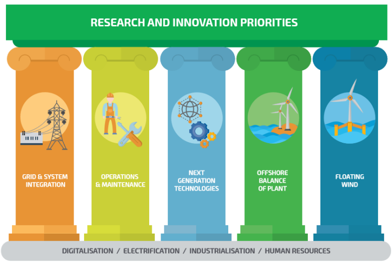


Figure 5 The 5 pillars of wind energy Research & Innovation.

1. Next generation wind turbine technologies and disruptive concepts

❖ Large technology developments are being realised and foreseen while wind energy is being implemented in large numbers (6000GW wind power worldwide implementation). EERA partners work on next generation wind turbines, the outcome is used by industry for product development. New concepts require major support at higher TRLs (demonstration at full scale in R&D context) to overcome the inertia of existing concepts.

Key action areas

- Develop next generation test and validation methods
- Investigate smart turbine design
- Removing barriers towards 20+MW turbines
- Develop disruptive technologies
- New materials and optimized structures

2. Grid integration and energy systems

- R&I must contribute to the transition towards 100% RES power systems, understanding the challenges and developing the required technical capabilities. This includes aspects such as offshore grid development and operation at North Sea scale, dynamic stability of electricity systems with very large penetration of power-electronic converters and maintaining a secure and affordable energy provision through developing markets and ancillary services, hybrid renewable energy systems, sector coupling and energy conversion and storage.

Key action areas

- Design and control of wind power plants for 100% RES power system
- Power market design, energy management and balancing
- Sustainable hybrid solutions, storage and conversion
- Increased performance of wind power via digitalization

3. Sustainability, Social Acceptance, Economics and Human Resources

- Massive deployment of wind power must be done in a sustainable manner, creating maximum value for stakeholders, including citizens, users and investors with respect to the Sustainable Development Goals. This is achieved by taking away barriers to massive deployment and ensuring sufficiently qualified human resource.

Key action areas

- Identify the most promising areas for value creation by wind energy in the future
- Standardised methods for quantitative impact assessments in research projects
- Research-based and targeted continuing education and training
- Recycling and circular economy
- Show-case best practices to empowering citizens and public engagement in wind power projects

4. Offshore wind (bottom fixed + floating)

- Massive offshore implementation of wind power requires R&I to further reduce risks and costs, thus accelerate deployment. Developments will occur further offshore and in deeper water requiring floating wind power. Integrated design methods needs to be developed which includes wind and waves, electrical infrastructure, environment, substructures, control, logistics and risks.

Key action areas

- Enabling floating wind
- Experiment for validation of design and multi-disciplinary optimization models for offshore wind farms (floating and fixed). Creating open access data sets.
- Understanding and modelling offshore physics for wind farm design and operation
- Understanding the mechanical and electrical design conditions for electrical infrastructure for floating wind farms

5. Operation and maintenance

- In order to reduce the cost of wind power, operation and maintenance must be optimized. Robotics solutions should reduce the required human intervention and sensor system provide the information for improved monitoring and control to increase life. The abundance of data and information should be used in big-data analytics technologies to improve O&M.

Key action areas

- Development and validation of models of component and structural damage and degradation as functions of loads and environment
- Next generation of Wind farm control
- Enable digital transformation in wind energy system O&M
- Sensor systems and data analytics for health monitoring
- Robotics

6. Fundamental Wind Energy Science

- Research in the fundamental wind energy sciences is required to develop the research competences and the underpinning scientific knowledge to improve standards, methods and design solutions. Also models and experimental data are needed for complex sites and extreme climates, larger and relatively lighter turbines, more efficient wind farms and large-scale penetration in the energy system. The research leads to updated standardized design criteria and standardized methods for testing and validation.

Key action areas

- Efficient multi-disciplinary optimization and system engineering
- Multi-scale flow modelling
- Large rotor aerodynamics
- Digitalization and data analytics
- Materials science
- Construction and manufacturing
- Open access database for research validation
- Integrated Multi fidelity system

THANK YOU

PETER EECEN
COORDINATOR EERA JP WIND

For more inspiration:
TNO.NL/TNO-INSIGHTS

innovation for life

EERA JP Wind *R&I strategy* 2019

I. Introduction to the EERA JP Wind R&I Strategy 2019

II. Research Agenda topics:

1) Next generation wind turbine technologies and disruptive concepts
2) Grid integration and energy systems
3) Sustainability, Social Acceptance, Economics and Human Resources
4) Offshore wind (bottom-fixed and floating)
5) Operation and maintenance
6) Fundamental Wind Energy Science

EERA JP WIND

EERA JP Wind brings together the major public research organisations in Europe with substantial research and innovation efforts in wind energy and consists of **53 partners.**

Mission

To provide strategic leadership for medium to long-term research and to support the European wind energy industry and societal stakeholders.

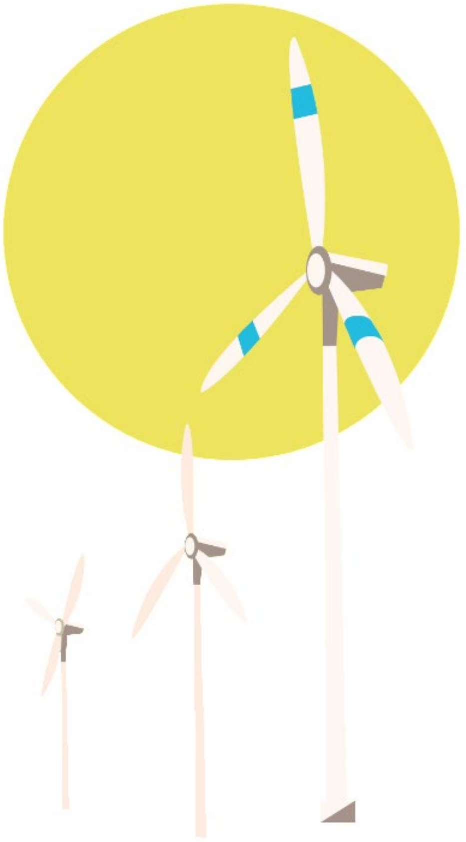
EERA JP Wind aims to provide the following **benefits** to its partners:

> **Support R&D managers** in institutions with significant wind energy R&D in shaping their research strategies according to European and national priorities and build the network to execute it. In EERA JP Wind we work together, to develop and understand the key research priorities for the European wind energy sector and implement it through joint projects or in national research programmes.

> **Influence EU strategic research priorities.** EERA JP Wind aims to be the most important platform to engage in EU Strategic research priority setting. This will happen directly via EERA JP Wind as well as in collaboration with national partners and the European Technology and Innovation Platform for Wind Energy (ETIPWIND).

> **Access a unique pool of knowledge, data and research facilities.** The members of EERA JP Wind are the main organisations for public wind energy R&D in Europe. That creates a unique knowledge pool and a platform for sharing and accessing data and research facilities.

> **Being part of globally leading network of wind energy researchers.** EERA JP Wind provides its members with a potential global outreach to collaborative partners around the world.



EERA R&I strategy 2019 – topics

EERA JP Wind has defined the priority topics, challenges and key action areas for wind energy research. The resulting R&I strategy is the result of discussions with the **53 major European research groups** organized in EERA JP Wind. Six urgent and important **topics** have been identified:

1. **Next generation wind turbine technology & disruptive concepts** - Large technology developments are being realised and foreseen while wind energy is being implemented in large numbers. The wind sector requires a strong scientific knowledge base to develop wind energy generators beyond its capabilities of today and tomorrow. New concepts contribute to the massive deployment but require major support at higher TRLs to overcome the inertia of existing concepts.
2. **Grid integration and energy systems** - R&I must contribute to the transition towards 100% RES power systems, understanding the challenges and developing the required technical capabilities. This includes aspects such as dynamic stability of systems with very large penetration of converters, market designs and interactions with other energy systems, sector coupling, energy conversion and storage.
3. **Sustainability, social acceptance and human resources** - Massive implementation of wind power must be done in a sustainable manner, creating maximum value for stakeholders, including investors, users and citizens with respect to the Sustainable Development Goals. This is achieved by taking away barriers to massive deployment and ensuring sufficient qualified human resource.
4. **Offshore wind (bottom fixed + floating)** - Massive offshore implementation of wind power requires R&I to further reduce risks and costs, thus accelerate deployment. Developments will occur further offshore and in deeper water requiring floating wind power. Integrated design methods needs to be developed which includes wind and waves, electrical infrastructure, environment, substructures, control, logistics and risks.
5. **Operation and maintenance** - In order to reduce the cost of wind power, operation and maintenance must be optimised. Robotics solutions should reduce the required human intervention and sensor system provide the information for improved monitoring and control to increase life. The abundance of data and information should be used in big-data analytics technologies to improve O&M.
6. **Fundamental wind energy science** - Research in the fundamental wind energy sciences is required to develop the research competences and the underpinning scientific knowledge. This leads to improved standards, methods and design solutions. Models and experimental data are needed for complex sites and extreme climate, larger and lighter turbines, more efficient wind farms and large-scale penetration in the energy system.

EERA R&I strategy 2019 – Contribution to SET Plan and SDGs

The EERA JP Wind R&I strategy contributes to the **European Strategic Energy Technology Plan (SET Plan)** as well as to the **Sustainable Development Goals (SDGs).**

SET Plan: The EU is committed to becoming the global leader in renewable energy technology and realise an CO2-free energy system. The EU Energy Roadmap 2050 aims to ensure a clean, competitive and reliable energy supply. The SET Plan aims to accelerate the development and deployment of low-carbon technologies. It promotes research and innovation efforts across Europe by supporting the most impactful technologies in the EU's transformation to a low-carbon energy system.

SDGs: The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States in 2015, providing a shared blueprint for peace and prosperity for people and the planet, now and into the future. The 17 SDGs are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

EERA R&I strategy 2019 – Connection to other strategies

The partners in EERA JP Wind are working on wind energy research and development that will keep Europe in the forefront of the world's pre-competitive wind energy research and maintain Europe's innovative wind industry.

EERA JP Wind works closely with ETIPWind, the industry platform that connects Europe's wind energy community, and EAWE, the European Academy of Wind energy, an academic research community of research institutions and universities in Europe.

Both **ETIPWind** as **EAWE** have published their research strategies. The R&I strategy of EERA JPWind is strongly connected. However, each strategy has its own purpose and application: where the ETIPWind strategy primarily aims at higher technology readiness levels (TRL), the EAWE strategy primarily focusses on fundamental research topics at low TRL.

The EERA JP Wind strategy aims at research that is required to bring the results of more fundamental research into applications. The result is a research scope on TRL3 to TRL8 with strong focus on applicability to industry and product development. The innovations that are the result support the industry. A successful and leading European wind industry requires the support from expert groups in short, medium and long-term research activities and requires a research strategy at all three levels.

ETIP Wind
EUROPEAN TECHNOLOGY & INNOVATION PLATFORM ON WIND ENERGY

eawe
european academy of wind energy

1. Next generation wind turbine technologies and disruptive concepts

- **Large technology developments are being realised and foreseen while wind energy is being implemented in large numbers (6000GW wind power worldwide implementation). EERA partners work on next generation wind turbines, the outcome is used by industry for product development. New concepts require major support at higher TRLs (demonstration at full scale in R&D context) to overcome the inertia of existing concepts.**

- Research gaps:
  - Implementation of 6000GW wind power worldwide requires more cost efficient, efficient, low environmental impact, scalable wind energy converters.
  - Degradation and damage mechanisms of materials and components
  - Unknowns in degradation mechanisms (f.i. wear in blades and drivetrain, erosion of blades) lead to unexpected behavior and limited options for cures.
  - Access to and data from a wind turbine research infrastructure
  - Upscaling of wind turbines and aiming for further cost reduction require validation of models and innovations to reduce uncertainties in design. Data sets are lacking.
  - Interpretation and extrapolation of scaled, hybrid and component testing
  - The development of larger and larger turbines require major innovations in the certification and testing methodologies such as scaled testing and testing of components together with virtual tests and development of international standardisation.
  - Multi-purpose platforms integrating various options such as wind, solar, wave, tidal, seaweed, etc.

Key action areas

- **Develop next generation test and validation methods**

Development of external condition measurement methods, in addition or alternative to full-scale blade testing, test benches for drivetrain testing, tailor-made wind tunnel models and improvements in material testing. Testing and validation methods for components shall be developed and proposed for international standardisation. Develop an integrated, full-scale international testing environment.

- **Investigate smart turbine design**

Development of smart rotor technology to reduce loads, smart materials to reduce degradation, self-repair technology and intelligent, adaptive turbine controllers.

- **Removing barriers towards 20+MW turbines**

Barriers in blade design and testing, rotor-hub design, drivetrain design must be addressed including the installation of large and heavy **components.**

- **Develop disruptive technologies**

Investigating game changers and new technology solutions in rotor, drive train, support structures and electrical system keeping a close watch to technology developments in other disciplines and completely different concepts like high-altitude wind power.

- **New materials and optimized structures**

Introducing smart materials, such as nano-coatings, high-strength materials, anti-corrosion materials and self-healing materials. Structural reliability methods need to be developed in order to better use materials, predicting damage and cracks in an enhanced way. Solutions for leading edge erosion needs to be developed.

2. Grid integration and energy systems

- **R&I must contribute to the transition towards 100% RES power systems, understanding the challenges and developing the required technical capabilities. This includes aspects such as offshore grid development and operation at North Sea scale, dynamic stability of electricity systems with very large penetration of power-electronic converters and maintaining a secure and affordable energy provision through developing markets and ancillary services, hybrid renewable energy systems, sector coupling and energy conversion and storage.**

- Research gaps:

  - **Adaptation of electricity markets for a 100% RES power systems.** When production of wind and solar will dominate the markets, their production characteristics must be matched by market design, including more local and short-term flexibility markets, with faster dispatch and adequate pricing
  - **Validated energy systems models for assessing the value of wind power** with 100 % variable renewable energy supply. Various scenarios / hourly timestep models exist, but with more or less crude assumptions, e.g. on wind variations, balancing capabilities, regional transportation bottlenecks, etc.
  - **Degradation and failure mechanisms of cables, transformers and power electronic converters** call for extensive research and testing to be fully understood and enable reliable grid solutions, including mitigating measures.
  - **Behavior and control of large HVDC connected clusters** is vital for enabling future development of large interconnected offshore grids, serving to connect wind farms to different national markets and offshore loads, as well as power/energy exchange between regions. Essential aspects are strategic grid planning, optimal power flow, reliable operation and protection schemes and supporting the interconnected terrestrial grids.
  - **Dynamic performance of very large wind power clusters** need to maintain power quality and stability in offshore wind farm grids that are fully based on power-electronic converters in order to guarantee reliable and efficient wind farm operation.
  - **Advanced system services from wind power**, providing reserve power for frequency support, reactive power for (dynamic) voltage support, mitigate or actively compensate harmonics for maintaining power quality and providing black start (grid forming operation) for increasing security of supply and helping system restoration, etc.

Key action areas

- **Design and control of wind power plants for 100% RES power system**

Technical solutions to enable wind power plants to enabling safe and efficient power system operation with 100% renewable generation

- **Power market design, energy management and balancing**

The energy system transition requires development of tools for energy management, taking into account wind forecast uncertainty, and supporting the interaction between wind power, other generation, conversion and storage, demand-response and grid capacity limitations.

- **Sustainable hybrid solutions, storage and conversion**

Combining offshore wind with other renewables, utilizing complementary generation patterns, contributes to improving the security of supply and lowering grid integration costs. Conversion and storage is essential to realize the required generation flexibility and security of supply, both on the short term as well as seasonal. Furthermore, integrating of these solutions in offshore wind farms is needed to facilitate their large-scale and economic integration, including off-grid approaches, i.e. using gas or other alternative energy carriers.

- **Increased performance of wind power via digitalization**

Use of field data, big data analytics and AI combined with system modelling for monitoring, control and performance optimization of wind power in the energy system.

3. Sustainability, Social Acceptance, Economics and Human Resources

- **Massive deployment of wind power must be done in a sustainable manner, creating maximum value for stakeholders, including citizens, users and investors with respect to the Sustainable Development Goals. This is achieved by taking away barriers to massive deployment and ensuring sufficiently qualified human resource.**

- Research gaps:
  - Wind can create higher value for society, both on the market side (high value energy at low cost), on the societal side (socio-economic benefits, avoiding negative impacts), depending on the interactions between market, technological, environmental issues within the overall policy and regulatory framework
  - Contribution of wind energy to the UN Sustainable Development Goals (SDG)
  - Applying life-cycle assessment and estimating requirements of resources for the energy transition, including the availability of resources in power systems with very high shares of wind energy
  - Assessing the economic and societal impact of research and innovation projects for wind energy
  - Technologies and designs to improve recycling and end-of-life solutions
  - Transfer understanding of mechanisms behind social acceptance into implementable approaches and demonstrate their value for project realisation
  - Identify skills and training needs required for developing and handling future wind turbine designs and develop best practices for high quality training programs

Key action areas

- **Identify the most promising areas for value creation by wind energy in the future**

Assessment of new ideas such as alternative routes to market (e.g. through hydrogen production), regulation and market design (e.g. to reduce barriers, financial mechanisms to support wind investment…), new business models (e.g. aggregator services), profit-sharing mechanisms (e.g. local ownership schemes).

- **Standardised methods for quantitative impact assessments in research projects**

Development Develop a method for broader socio-economic impact assessments in project proposals (including cost indicators and value creation indicators).

- **Research-based and targeted continuing education and training**

Adequate human resources with the right skills and competences are key to Europe's continued global leadership in wind energy. New skills are required as the technology evolves.

- **Recycling and circular economy**

As wind power increases its share in the energy mix, it needs to address issues related to its environmental and social footprints. An environmental and community friendly design also includes the 'afterlife' of a turbine. We need to develop technologies that are easily recyclable, create designs that are good for recycling and embrace circular economy concepts in our research and development.

- **Show-case best practices to empowering citizens and public engagement in wind power projects**

Extensive wind onshore deployment is increasingly impacting citizens, who need be included in the planning and design process. During the past years, we have started to understand mechanisms and solutions for effective participatory processes and create acceptability. We now need demonstration projects on how to build the 'acceptable' onshore wind plant.

4. Offshore wind (bottom fixed + floating)

- **Massive offshore implementation of wind power requires R&I to further reduce risks and costs, thus accelerate deployment. Developments will occur further offshore and in deeper water requiring floating wind power. Integrated design methods needs to be developed which includes wind and waves, electrical infrastructure, environment, substructures, control, logistics and risks.**

- Research gaps:

  - **Validation of integrated design models for floating wind plants** is needed to ensure cost effective designs and to maximize the opportunities for floating foundations optimization based on wind turbine load control technology.
  - **Efficient multi-disciplinary optimization** offers to achieve cost effective and reliable foundations, accounting for a wide range of design parameters and needs research and maturing. Platform and mooring lines maintenance strategy.
  - **Offshore physics (soil damping, breaking waves, soil-structure-fluid interaction, air-sea interaction).** The limited understanding of physics phenomena and model uncertainties affecting offshore balance of plant technology prevents accurate design models and optimal cost-effective designs. Proper data sets are lacking.
  - **Site-specific structural and electrical design conditions for electrical infrastructure** are lacking to better understand the loading and operational conditions of key electrical components like cables or power converters, enabling improvements in reliability.

Key action areas

- **Enabling floating wind**

Develop design model for integrated aero-hydro-elastic optimisation including cost optimisation. Develop technology to enhance mass-production and installation of floating platforms. Develop smart and disruptive solutions for (dynamic) mooring.

- **Experiment for validation of design and multi-disciplinary optimization models for offshore wind farms (floating and fixed). Creating open access data sets.**

Execute large-scale floating experiment to create open access experimental datasets for effective design model validation and uncertainty calculations, leading to faster improvements of design tools and more accurate designs. Develop an effective coupling of offshore design models (i.e. balance of plant - wind turbine) and metocean models to enable overall system optimization.

- **Understanding and modelling offshore physics for wind farm design and operation**

The improvement of models focused on key physical phenomena (i.e. soil-structure-fluid interaction) is needed to develop better design tools for industry, able to capture a broader spectrum of failure modes.

- **Understanding the mechanical and electrical design conditions for electrical infrastructure for floating wind farms**

Develop more accurate and site-specific load models accounting for metocean conditions (i.e. hydrodynamic forces on dynamic cables) as well as the electrical operational conditions and interactions for improved layout including connections, transformers and inter-array cables.

5. Operation and maintenance

- **In order to reduce the cost of wind power, operation and maintenance must be optimized. Robotics solutions should reduce the required human intervention and sensor system provide the information for improved monitoring and control to increase life. The abundance of data and information should be used in big-data analytics technologies to improve O&M.**

- Research gaps:

  - **Accurate reliability models of components as functions of operation and loads.** Condition based maintenance or replacement of (sub)components relies on accurate reliability models that can predict remaining lifetime or probability of failure for a given load history.
  - **Degradation mechanisms of surfaces (wear, erosion and corrosion).** Unknowns in degradation mechanisms (f.i. wear in blades and drivetrain, erosion of blades and corrosion of support structures) lead to unexpected behaviour and limited options for cures.
  - **Lifetime extension** – is an effective solution for reduction of LCOE reduction as well as impact to environment and resources.
  - **Data analytics for O&M purpose and lifetime health prediction for predictive maintenance.** Abundant information and data are available from wind farms, for which processing by big-data analytics technology needs to be developed.
  - **Robotics –** Reduction to human presence at offshore platforms at large height to improve health and safety by automated and remote inspections and repair inside the nacelle as outside the turbine.

Key action areas

- **Development and validation of models of component and structural damage and degradation as functions of loads and environment**

  The fundamentals and results of damage and degradation need to be developed from micro-scale to macro-scale level. Validation requires extensive testing programmes.

- **Next generation of Wind farm control**

  Advanced (including data-driven, model-free, AI, etc) and holistic multi-objective wind farm control optimizing overall performance.

- **Enable digital transformation in wind energy system O&M**

  The abundance of available data requires big data analytics and applying real time testing and ”digital twins” to be developed to recognize patterns and improve energy yield and control degradation.

- **Sensor systems and data analytics for health monitoring**

  Robust, reliable, accurate and durable sensors need to be developed to monitor the condition and degradation of the most critical components and external conditions against lowest costs. Self-diagnostic systems and multi-sensor constructions may include remote sensing of external conditions and damage such as lidars, drones etc.

- **Robotics**

  Remote and automated repair technology and strategy requires the development of sensor technology and robotic solutions. These should be tested in safe demonstration environments as well as in the dynamic wind turbine environment.

6. Fundamental Wind Energy Science

- **Research in the fundamental wind energy sciences is required to develop the research competences and the underpinning scientific knowledge to improve standards, methods and design solutions. Also models and experimental data are needed for complex sites and extreme climates, larger and relatively lighter turbines, more efficient wind farms and large-scale penetration in the energy system. The research leads to updated standardized design criteria and standardized methods for testing and validation.**

- Research gaps:

  - **Climate change and extreme** climate affect the design, performance and operation. The development in critical geo-physical condition in the future needs to be modelled and assessed.
  - **Atmospheric multi-scale flow from meso-scale to wind farm flows** i.e. accurate and validated model predicting properties of flow in complex terrain regions down to wind farm flow affected by wakes and turbine control.
  - **Physics of large rotor aerodynamics: inflow, blade and wake aerodynamic characterization** i.e. accurate model development for the flow around large blades including add-ons and active flow devices and wake models.
  - **High performance computing and digitalization** call for extensive research and testing to be fully applied and enable accurate and reliable solutions.
  - **Materials, including better knowledge of properties, new and improved materials and their degradation and failure mechanisms,** provide new opportunities for weight and cost reductions, higher reliability and improved manufacture of wind energy systems.
  - **System engineering models, including detailed fluid-structure, soil-structure and electro-mechanical interaction** needs development in order to allow optimal design and operation for reduced LCOE and system compliance

Key action areas

- **Efficient multi-disciplinary optimization and system engineering**

  Optimisation of wind farm design requires a multi-disciplinary, system engineering approach including rotor, nacelle, tower, support structure, electrical infrastructure, soil, environment, markets and regulations and includes public acceptance as well as societal costs and benefits. Tools needs to be developed and matured, taking into account the complete lifecycle.

- **Multi-scale flow modelling**

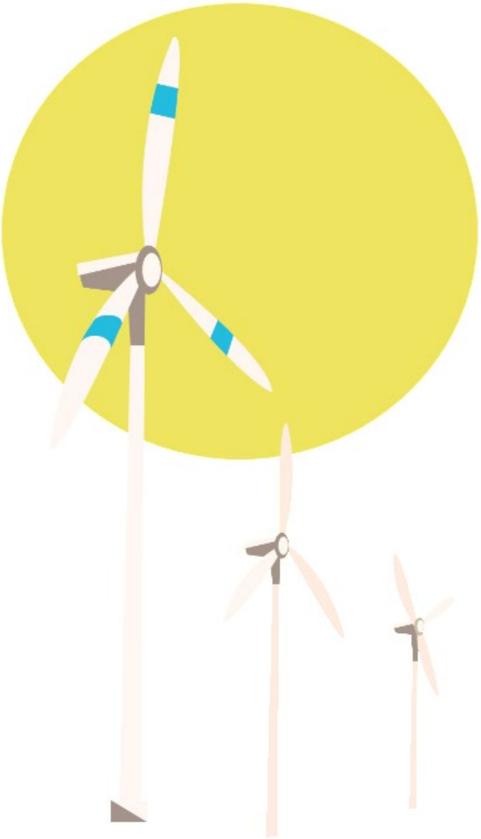
  Multi-scale modelling using high fidelity and high-performance computing to provide accurate estimates for siting, control, performance and operation of wind farms as well as predictions of effects from climate change and extreme climates.

- **Large rotor aerodynamics**

  Aerodynamic modelling at High Reynolds number, from high fidelity to engineering tools. Subsystem validation in wind tunnels and real-full scale wind turbine aerodynamic experiment measuring inflow, blade flow and the wake for model validation. This provides accurate power performance, loads and input for control.

- **Continued on next page**

6. Fundamental Wind Energy Science – Key action areas



Key action areas continued

- **Digitalization and data analytics**

  New sensors, data processing, machine learning and data analytics and methods for implementation in data-driven design, digital twins, control and monitoring for O&M needs development for increased reliability and reduced costs in wind energy.

- **Materials science**

  Better and more accurate knowledge of properties, behavior, degradation and damage mechanisms of materials as well as development of new materials or treatments to offer less conservative and more reliable designs needed for upscaling, cost reduction, circularity and lifetime extension. Material science is needed directed towards fracture mechanics, composite blades, structural elements, corrosive and erosive environment, mechanical and electrical components such as generators and magnets, subsea cables.

- **Construction and manufacturing**

  Relevant experiments need to be developed and implemented to create open access databases involving industry.

- **Open access database for research validation**

  Remote and automated repair technology and strategy requires the development of sensor technology and robotic solutions. These should be tested in safe demonstration environments as well as in the dynamic wind turbine environment.

- **Integrated Multi fidelity system**

  Global high fidelity system models provide insights in critical interaction between system components, i.e. for the drive train components and engineering tools offer total system optimization of wind energy plants, while being essential for the development of reduced order engineering design tools for technology and plant design.