



SET-Plan

Offshore Wind Implementation Plan

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Summary

The Offshore Wind Temporary Working Group (TWG) is composed of representatives of relevant countries and stakeholders, representing both the industry and academia. It identified research and innovation (R&I) activities as well as non-technical barriers/enablers, important to the further development of fixed¹ and floating offshore wind, which were included in this Implementation Plan (IP). The IP identifies the following 9 priority actions (both technological and non-technological) and is accompanied by a detailed activity fiches (see Annex 1) with resources, targets and ownership:

- 1 System Integration
- 2 Wind Energy Offshore Balance of Plant
- 3 Floating Offshore Wind
- 4 Wind Energy Operation and Maintenance
- 5 Wind Energy Industrialisation
- 6 Wind Turbine Technology
- 7 Basic Wind Energy Sciences
- 8 Ecosystem and Social impact
- 9 Human Capital Agenda

The actions are crucial to meet the SET-Plan targets for offshore wind energy listed in the Declaration of Intent². To ensure their proper implementation, a first estimation of the overall investment needed shows that EUR 1090 million should be mobilised, to be covered as follows:

- EUR 446.5 million coming from the private sector (41% of the total);
- EUR 375 million coming from national programmes (34% of the total);
- EUR 268.5 million coming from EU funds (25% of the total).

These figures are provisional and will need to be further investigated, validated and agreed during the implementation phase.

¹ Fixed offshore wind refers to offshore wind farms with fixed-grounded foundations (such as monopiles, jacket foundations, gravity-base foundations, tripods, tripiles, etc.)

² SET-Plan Declaration of Intent (20/01/2016): https://setis.ec.europa.eu/system/files/integrated_set-plan/declaration_of_intent_wind.pdf



Introduction

The integrated SET-Plan

The Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy (Energy Union strategy) is built on the ambition to achieve a fundamental transformation of Europe's energy system in a cost-effective way. This will be achieved by moving to more sustainable, smarter, more flexible, more decentralized, more integrated, secure and competitive ways of delivering energy to consumers. Most importantly, meeting this ambition will require that energy producers, transmission system operators (TSO) and suppliers innovate in terms of energy production, transportation and services. But also energy users will have to adapt to the new situation, as well as other stakeholders such as those people and parties that are affected by a change in energy source (mostly to electricity) or by the space that is required for the more (geographically) dispersed energy sources of the future. As innovation is the basis to the Energy Union, it is vital to support researchers and companies at key stages in the development of new products and processes.

The Strategic Energy Technology Plan (SET Plan) as part of the Energy Union strategy is at the forefront of European energy technology policy. The integrated SET Plan will identify those strategic priorities and actions needed to accelerate the EU energy system transformation in a cost-effective way. Renewable technologies are at the heart of the new energy system with offshore wind as a main pillar.

Europe's opportunities in Offshore Wind

Wind energy is the renewable energy technology expected to provide the largest contribution to the renewable energy targets for 2020 and beyond. Following a new record year in wind energy deployment in 2017, the EU's installed wind power capacity is at about 169 GW (at the start of 2018); with approximately 153 GW of onshore wind and with almost 16 GW located offshore. By 2020, the total installed wind energy capacity could reach 210 GW, which equals a capacity capable to supply 14% of electricity demand, and by 2030 wind energy deployment could reach 350 GW (of which 70 GW are foreseen as offshore wind). By 2030 wind energy could be supplying around 30% of EU's power demand³

This means that the responsibility of the wind sector to be a reliable source for electricity and also its social responsibility increases over time. The cost of onshore wind power is already competitive in a number of countries with other sources of electricity and the sector is now developing on the basis of its economic advantages.

Offshore wind represents a significant future opportunity: resources are stable and abundant and public acceptance is higher. Europe is the leader in offshore wind and the sector continues growing. In the North Sea and the Baltic Sea most experience is gained so far on bottom fixed turbines but more and more initiatives emerge to accelerate the development of floating devices, such as pre-commercial floating projects in the Mediterranean and the Atlantic (e.g. the 25 MW Windfloat project, etc.).

While in other regions of the world the offshore wind industry has just started to develop, European industries can count on more than 20 years of experience and on a continuous increase

³ Wind Europe: Wind energy in Europe, scenarios for 2030, September 2017.



at gigawatt-levels in additional annual capacity since 2012. As of January 2018 4150 offshore wind turbines in 94 wind farms across 11 countries in European waters are fully grid connected. Another 2.9 GW are awaiting connection and according to industry sources, there are 25 GW of consented offshore wind farms identified, and a further 65 GW of planned offshore wind farms are in the pipeline. Industry cost reduction targets for 2020 and thereafter could allow zero government contribution in the near future (if grid connection is not included). The recent outcomes of competitive offshore wind auctions in North-West Europe show a sharp decrease in LCoE bid prices which might be an indication for falling costs of offshore wind energy and prove the effect and pace of innovation and organization of the sector. At present, project developers already made offers for projects without governmental support (meaning that project developers will receive their revenues from the wholesale electricity market only). In these so called zero-bids, the developers presume that further cost reductions are still to be realized by major technological innovations. However, in the short to medium term zero support bids are only possible for specific developers on specific sites. Most offshore wind farms will need some form of revenue stabilization in the future.

In order to maintain European leadership, the competitiveness of the offshore wind energy sector must increase further. The TWG confirms that Europe should not focus only on fixed bottom offshore wind, but also on floating offshore wind. Floating wind will be essential for countries at the Atlantic coastline and in the Mediterranean and low LCoE targets will be a challenge.

According to the TWG three key issues need to be tackled:

- 1) Offshore wind costs must be reduced through, but not only, increased performance and reliability in order to meet its full potential contribution to the European energy mix.
- 2) There is a need to develop (floating) substructures or integrated floating wind energy systems for deeper waters and wind energy systems for use in other marine climatic conditions, to increase the deployment possibilities and to maintain and even improve the European position in the global market. Additional policy and research actions need to be developed.
- 3) The added value of wind farms should be increased. For offshore wind energy to become a reliable source of energy, system integration will become ever more important. To improve the societal acceptance the ecological impact and spatial planning are crucial elements for the future development of offshore wind. Synergies with the declining oil & gas sector and co-operation with blue economy sectors has to be found.

For the Mediterranean sea full deployment of the floating offshore wind technology should be considered. A game-changing competitiveness in this sea requires identifying the most suitable sea areas ensuring wide range of platforms operability. System integration should be considered (hybrid floating systems and energy island concepts combining wind with other green energy resources). It will enable the EU stakeholders to access and climb new promising markets around the world.



SET-Plan Strategic targets

The agreed strategic targets for offshore wind energy in the declaration of Intent were:

1. Reduce the levelised cost of energy (LCoE) at final investment decision (FID) for fixed offshore wind* by improvement of the performances of the entire value chain to less than 10 ct€/kWh by 2020 and to less than 7ct€/kWh by 2030.

2. Develop cost competitive integrated wind energy systems including substructures which can be used in deeper waters (>50m) at a maximum distance of 50 km from shore with a LCoE* of

o less than 12 ct€/kWh by 2025 and to

o less than 9 ct€/kWh by 2030, striving towards cost competitiveness

* the costs for delivering the electricity to onshore substations are taken into account within the levelised cost of electricity (LCoE)

Because of the ongoing developments in the sector the TWG agreed that the first target should be even more ambitious and a zero subsidy cost level should be targeted. The first target has been reformulated by the TWG to:

- 1) Reduce the levelised cost of energy (LCoE*) at final investment decision (FID) for fixed offshore wind by improvement of the performances of the entire value chain striving towards zero subsidy cost level for Europe in the long term.

These ambitious targets are associated with high reliability (going up to 98-99% for a single turbine), superior performance, and with much more cost-effective and innovative installation, maintenance, and logistics. To realize the cost targets a facilitating research and innovation framework needs to be accompanied by sufficiently large deployment volumes. In addition there should be a five year visibility on the volumes so that a stable supply chain can develop and the sector can benefit from economies of scale. It is obvious that high deployment rates are necessary to be able to meet above-mentioned targets. This is why active policies from the EU member states are necessary and at the same time increased system integration and added value are required. A minimum deployment rate of 4 GW per year in the North Sea and Baltic Sea only should be targeted. For floating wind the TWG expects that support schemes like NER300⁴ are still necessary in the short term as well as to ensure market introduction.

In the original Declaration of Intent for offshore wind the following areas of research and innovation (R&I) were included:

- Production value chain performance/cost competitiveness

Larger and lighter turbines (>10 MW while maintaining top-head mass below 50 t/MW); more reliable turbines (materials and components of better quality; condition monitoring and control strategies); lower-cost, fast deployment installations, including foundations, and improved cable laying and protection methods; development of lower cost interconnection systems. Substructures or integrated wind energy systems for water depths beyond 50 m and possibly in other climates conditions for instance for offshore wind farms in the Baltic Sea and Mediterranean.

- Production value chain

⁴ NER300 programme: https://ec.europa.eu/clima/policies/lowcarbon/ner300_en



Standardisation; better infrastructure for large scale deployment including appropriate and sufficient test and validation centers; effective methods for repowering and recycling; lighter, stronger and cheaper materials; new control and power electronics.

- Better system integration

Grid development (enhancing system security, grid integration) and reliability of the grid at very high levels of wind power penetration (e.g. up to 70% of the electricity demand); improving the accuracy of wind power forecasting to enhance better system integration..

- Wind conditions

Efficiency and accuracy of wind design conditions, siting, resource assessment and forecasting. An uncertainty of less than 3% in the forecasting is expected by 2030.

- Non technological aspects

A coordinated, continuous pipeline of offshore wind projects until 2030 enabling a continuous learning curve and cost reduction. New market designs and optimal business models for a power system with high shares of non-dispatchable renewables generation, improved financing conditions for wind energy projects especially reducing the cost of capital for offshore wind. Knowledge exchange (sharing best practice, seeking common solutions and standards, seeking common ground for economically viable investments).

- Environmental and societal issues

Knowledge on potential impacts of wind energy on the environment and development of cost-effective solutions to minimise it, increase social acceptance and support for wind energy.

The TWG took these actions as a starting point. Some of these actions are worked out in more detail in this Implementation Plan as priority actions (see Annex 1).

At this moment in time the TWG feels that these are the key issues, but is assumed that the agenda will change due to the progress in the future. This is why it is decided to work out a process for the short and medium term that enables an approach with a “rolling” agenda” and to focus on European cooperation. The plan should rather enable a continuous flow of cooperation opportunities than fully determine the commitments of all countries involved. Many of these actions (especially the development of larger turbines) are and will be taken up by industry.

In the definition of the priority actions, the Strategic Research and Innovation Agenda (SRIA) from the European Technology and Innovation Platform on Wind Energy⁵ (ETIPWind) and the subprogrammes of the European Energy Research Alliance⁶ Joint Programme (EERA JP) on Wind Energy were considered. In the SRIA of ETIP Wind the R&D focus is on 1) Grid infrastructure, integration and infrastructure; 2) Operation and maintenance; 3) Industrialisation; 4) Offshore balance of plant; 5) Next generation technologies). The subprogrammes (SP) of EERA JP on Wind Energy focus on 1) Wind Conditions; 2) Aerodynamics; 3) Structures and Materials; 4) Offshore Wind Energy; 5) Grid Integration; 6) Research Facilities; 7) Wind Integration – Economic and Social Aspects).

⁵ Strategic research and innovation agenda SRIA 2016; ETIPWind

⁶ EERA Joint Research Programme 2017



Offshore wind cooperation between the North Seas Countries

The SET-Plan Declaration of Intent was adopted in January 2016. In the forefront of the TWG's work on the Implementation Plan, a political declaration on the energy cooperation between the North Seas Countries⁷ has been signed in June 2016. Within this cooperation the development of an offshore grid linking the ten countries in the North Seas region (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the United Kingdom) is identified as a long-standing energy policy priority for the EU. The region has great potential for offshore wind generation, and linking these countries via energy infrastructure will create jobs and economic growth throughout the region. A regional, cooperative approach will deliver these benefits in the most cost-efficient manner.

Since the establishment of the [North Seas Countries' Offshore Grid Initiative](#) (NSCOGI) in 2009, the cost of offshore wind energy has decreased following the ever-increasing maturity of these technologies.

The declaration signed in 2016 is a good example of speeding up the development in the North-Western Region. The most pressing needs identified include harmonization in regulation, further innovation to enable an increasing role of offshore wind in the energy system, the use of common (cross-national) infrastructure, development of technology enabling low maintenance concepts, education and training to attract sufficient personnel and re-education of personnel that are looking for new jobs as traditional energy sources no longer require their contributions. This cooperation has two goals:

- facilitating the cost-effective deployment of offshore renewable energy, in particular wind energy
- promoting interconnection between the countries in the region.

The declaration emphasises the importance of voluntary cooperation, with the aim of securing a sustainable, secure and affordable energy supply for the Northern Seas countries.

Four specific work areas were identified:

- maritime spatial planning⁸
- development and regulation of offshore grids and other offshore infrastructure⁹
- support framework and finance for offshore wind projects¹⁰
- standards, technical rules and regulations in the offshore wind sector.¹¹

A Support Group was established for each specific work area. The involvement of a wide variety of stakeholders is ensuring concrete progress and tangible results.

⁷ <https://ec.europa.eu/energy/en/news/north-seas-countries-agree-closer-energy-cooperation>

⁸ https://ec.europa.eu/energy/sites/ener/files/documents/20161216_support_group_1_msp_web_version_final.pdf

⁹ https://ec.europa.eu/energy/sites/ener/files/documents/20161219_support_group_2_drog_web_version_final.pdf

¹⁰ https://ec.europa.eu/energy/sites/ener/files/documents/20161109_support_group_3_sff_web_version_final.pdf

¹¹ https://ec.europa.eu/energy/sites/ener/files/documents/20161003_support_group_4_strr_web_version_final.pdf



A High Level Group is bringing the outputs of the working groups to the political level and ensures that important decisions receive support.

The specific actions of working group 4 on standards, technical rules and regulations in the sector are listed below to illustrate the complexity and the variety of the work in offshore wind to reduce the LCoE.

1. The harmonisation of rules concerning aviation markings and lights
2. The harmonisation of health and safety requirements
3. The alignment of crew and vessel requirements
4. The mutual recognition and harmonisation of certification standards for components in offshore wind projects
5. Exchanging best practices on park layout constraints including line of sight requirements
6. The establishment of a common approach, for example by establishing facilities for innovation, testing and demonstration of new technology
7. Investigating a common approach to rules applicable to offshore turbines in territorial waters and exclusive zones.

The Temporary Working Group decided not to focus on the actions covered by working groups of the energy cooperation between the North Seas Countries, but agreed that this work is complementary to the priority actions in this Implementation Plan.



Priority actions (R&I Activities)

The process to define the priority technology actions (R&I Activities)

The core of the Implementation Plan is a selection of R&I activities to be carried out by the various actors (SET Plan countries, stakeholders and, within its mandate, the European Commission) in order to achieve the targets set in the DoI.

Since its installation in December 2016, the work of the TWG was mainly on the definition of priority R&I activities (See Annex 3). The selection of R&I priorities has been done in close co-operation with ETIP Wind and EERA. Both provided input for the implementation plan and attended the TWG meetings (see annex 2).

Priority actions presented in this Implementation Plan needed the involvement and support of at least two SET-plan countries.

The R&I Activities

The TWG elaborated a set of seven technology-related priority actions for the future development of offshore wind and two non-technology-related actions.

The seven technology-related R&I activities concern:

1. System Integration
2. Wind Energy Offshore Balance of Plant
3. Floating Offshore Wind
4. Wind Energy Operations and Maintenance
5. Wind Energy Industrialisation
6. Wind Turbine Technology
7. Basic Wind Energy Sciences

The two non-technological concern:

8. Ecosystem, and Social Impact
9. Human Capital Agenda

For each action, ongoing R&I activities supporting the strategic targets (conducted at national and/or at European level and/or by industry) are identified. For each action several subactions with concrete targets/deliverables are defined. An overview of all the (sub-)actions is listed in Table 1. The TRL range of the actions, the timeline and the expected private, national and EU funding in millions of euro are shown as well. All these actions will contribute to the overall strategic targets for offshore wind to reduce the levelised cost of energy.



Table 1: Overview of Priority Actions and subactions indicating the TRL range of the actions, the timeline and the expected private, national and EU funding in millions of euro.

OVERVIEW				Total	EC	MSs	Private
ALL ACTIONS				1090	266,5	372	446,5

PR1	Action	TRL	timeline	Total	EC	MSs	Industry
System Integration							
1	Electrification of an existing gas production platform	6-9	2018-2023	10	0	5	5
2	Gas2Wire	6-9	2018-2026	10	0	5	5
3a	Power to Gas and Hydrogen Production - phase 1	3-6	2019-2021	5	2	3	0
3b	Power to Gas and Hydrogen Production - phase 2	6-9	2022-onwards	40	10	15	15
4a	Energy storage in depleted gas fields (CAES or Hydrogen) - phase 1	1-3	2019-2021	5	2	3	0
4b	Energy storage in depleted gas fields (CAES or Hydrogen) - Phase 2	3-6	2020-2024	25	5	10	10
5	Development of cost-effective solutions for the integration of wave and wind energy production	1-7	2019-2021	5	3	2	0
6	Concept development of an artificial energy island	2-5	2018-2020	15	3	12	0

PR2	Action	TRL	timeline	Total	EC	MSs	Industry
Wind Energy Offshore Balance of Plant							
1	Lifecycle cost optimization for installation and Balance of Plant for deeper water wind farm sites	3-7	2018-2024	5	1,5	1,5	2
2	Understanding and modelling offshore physics for wind farm design and operation	3-7	2018-2024	5	3	2	0
3	Experiment for open access data set for validation of design models for offshore wind farms	3-7	2018-2024	10	5	4	1
4	Validated model chain for system engineering and multi-disciplinary optimization (floating and fixed)	3-7	2018-2024	5	2	2	1
5	Mechanical and electrical design conditions for electrical infrastructure	3-7	2018-2024	5	0	2,5	2,5



PR3	Action	TRL	timeline	Total	EC	MSs	Industry
	Floating Offshore Wind						
1a	Concept Development of cost effective multi-MW multipurpose modular floating platforms made of concrete or steel.	2-6	2018-2020	20	9	11	0
1b	Development of cost effective multi-MW modular floating platforms made of concrete or steel.	6-9	2020-2026	150	30	70	50
2a	New concept manufacturing procedures and standardisation of floating platforms	2-6	2018-2020	10	3	7	0
2b	Development of manufacturing procedures and standardisation of floating platforms	6-9	2020-2027	50	5	25	20
3a	Concept Development of advanced mooring systems	2-6	2018-2020	10	4	6	0
3b	Development of advanced mooring systems	6-9	2020-2028	50	10	20	20
4	Integrating Floating Platforms - Engineering tools development & validation	5-6	2018-2020	2	1	1	0
5	Comparative study of different support structures for floating wind turbines for specific EU sites (Med Sea, Atlantic Ocean).	7-8	2018-2020	1	0	1	0

PR4	Action	TRL	timeline	Total	EC	MSs	Industry
	Wind Energy Operation and maintenance						
1	Sensors and data analytics for health monitoring	3-7	2018-2022	4	2	1	1
2	Sensor systems for performance measurements and condition monitoring	2-5	2018-2022	10	5	5	0
3	Enable digital transformation in wind energy system O&M	2-5	2018-2022	10	4	3	3
4	Development and validation of models of component and structural damage and degradation as functions of loads and environment	2-5	2018-2022	4	2	2	0
5	Use of unmanned or autonomous vehicles (in air or underwater) and the use of robotics	2-5	2018-2022	15	7	8	0



PR5	Action	TRL	timeline	Total	EC	MSs	Industry
Wind Energy Industrialisation							
1	Standardised methods for quantification of site and system conditions	4-7	2018-2025	20	5	5	10
2	Numerical and test methods for accurate assessment of system and component reliability	2-7	2018-2025	10	4	4	2
3	Validated model chain for system engineering and multi-disciplinary optimization	2-4	2018-2025	10	4	4	2
4	Design for manufacturing, construction and decommissioning	2-7	2018-2025	15	4	4	7

PR6	Action	TRL	timeline	Total	EC	MSs	Industry
Wind Turbine Technology							
1	Disruptive technologies	3-7	2018-2025	15	10	5	0
2	Next generation test and validation methods	3-7	2018-2025	10	5	5	0
3	optimized structures using innovative materials	3-7	2018-2025	20	7	7	6
4	Wind farm control	3-7	2018-2025	10	0	5	5
5	Demonstration of large scale turbines > 10 MW	6 - 9	2018-2022	200	20	20	160
6	Demonstration of turbines bigger than 15 MW	6 - 9	2021-2025	150	20	20	110

PR7	Action	TRL	timeline	Total	EC	MSs	Industry
Basic Wind Energy Sciences							
1	Offshore Measurements Platforms	2-4	2018-2025	15	6	9	0
2	Multi-scale flow modelling	2-4	2018-2025	15	7	8	0
3	Integrated system-engineering tools	2-5	2018-2025	15	8	7	0
4	Digitalisation and data analytics	2-7	2018-2025	25	10	10	5
5	Material science	2-5	2018-2025	20	10	10	0



PR8	Action	TRL	timeline	Total	EC	MSs	Industry
	Ecosystem and social impact						
1a	Water treatment in offshore windfarms for Crab and lobster cultivation	6-9	2018-2020	3	1	2	0
1b	Research on impact of Sea weed farming on wind energy farms	6-9	2018-2020	3	1	2	0
1c	Artificial reefs for oysters	6-9	2018-2020	3	0	3	0
2	Concept development floating wind farms, acceptability and multifunctional uses	6-9	2018-2025	5	2	2	1
3	Feasibility study on offshore research infrastructure development: social, environmental, coexistence and multi-use, legal aspects.	6-9	2018-2025	5	2	2	1
4	EU coordinated monitoring of impacts of wind farms during installation and operation	6-9	2018-2025	15	9	3	3

PR9	Action	TRL	timeline	Total	EC	MSs	Industry
	Human Capital Agenda						
1	Marie Curie ITN projects focusing on the education of PhD candidates working of FOWT		2018-2025	5	5	0	0
2	European Centre of Excellence for OWT		2018-2025	15	10	5	0
3	Wind Energy Hubs		2018-2025	5	0	5	0



Funding of the priority Actions

It should be noted that through this plan, the TWG provides only an estimate of the funding required for the priority actions. These figures are initial estimates and will need to be investigated, validated and agreed during the implementation phase.

In the Table below the estimates are presented for each priority action. A breakdown is shown about the funding sources: EU, national and private funding.

Table 2: Summary of total costs and funding for each Priority Actions indicating the total expected private, national and EU funding in millions of euro and the total share in %.

Priority Action	Total (M€)	EU funding (M€)	National funding (M€)	Private funding (M€)	EU Funding (%)	National funding (%)	Private funding (%)
1 System Integration	115	25	55	35	22%	48%	30%
2 Wind Energy Offshore Balance of Plant	30	11,5	13	5,5	38%	43%	18%
3 Floating Offshore Wind	70	12	38	20	17%	54%	29%
4 Wind Energy Operation and maintenance	43	20	19	4	47%	44%	9%
5 Wind Energy Industrialisation	55	17	17	21	31%	31%	38%
6 Wind Turbine Technology	405	62	62	281	15%	15%	69%
7 Basic Wind energy sciences	90	41	44	5	46%	49%	6%
8 Ecosystem and social impact	34	15	14	5	44%	41%	15%
9 Human Capital Agenda	25	15	10	0	60%	40%	0%
Total budget required all actions (million €)	1090	268,5	375	446,5	25%	34%	41%

To ensure their proper implementation, an estimated overall investment of EUR 1090 million shall be required to be mobilised. The, provisional estimate of contributions per funding source is as follows:

- EUR 446.5 million coming from the private sector (41% of the total funding)
- EUR 375 million coming from national programmes (34% of the total funding)
- EUR 268.5 million coming from EU funds (25% of the total). funding)

Long term commitments could not be given by the members of the TWG, but based on the investments in wind R&I in the past years the TWG believes that it would be possible to realise these investments during the implementation phase. Annex 3 provides a preliminary overview of possible funding sources. In the description of the priority actions (Annex 1) additional information on existing funding sources is provided.



Next steps

This implementation phase and the following adoption of the implementation plan will build on the experience of the relevant SET-Plan stakeholders like such as the EC, Member States, WindEurope, ETIPWind, EERA JP Wind and EAWE. Members of the Temporary Working Group expressed their interest to continue their cooperation.

An implementation working group will be established to further advance the offshore wind Implementation Plan with the aim of reaching collectively the targets that will place Europe at the forefront of the offshore wind market. Implementation tasks include the monitoring of progress of actions defined in the IP. A functional support and monitoring methodology still has to be developed together with the SET-Plan steering committee.

Possible monitoring activities might include:

1. To carry out an annual mapping on the status of priority actions and the funding activities
2. Request each SET-plan country to complete a register of funded projects and ensure that funding recipients complete a report that captures LCoE progress. The format of reporting and details required will be developed by the working group and agreed by all stakeholders.
3. Request each country and relevant sector stakeholders to report separately on their activities under each priority action as part of the annual review.
4. ...

Possible support activities might include:

1. To organise on each priority action a yearly workshop with research coordinators from the private and public sector to stimulate collaboration and knowledge transfer.
2. To organise brokerage events to stimulate supply chain development and research collaboration.
3. Increased budgets on EU and Member States level for the support of Research and Innovation actions in offshore wind energy technology development.
4. ...

Depending on the results considerable extra efforts and funding might be required over the coming years to meet the goals of the Declaration of Intent. The actions included in this Implementation Plan have gathered consensus and interest but in the future may need to be better focussed and budgeted. Some actions need more applicative details (deliverables, planning etc.) to enable their direct use in joint calls or in collaboration activities among member countries. Further work on this Implementation Plan is therefore expected.

The TWG recognises that there is a need to support and monitor the operational actions to ensure the progress of the offshore wind sector and also to adapt the Implementation Plan. Having finalised the Implementation Plan, the work of the Offshore Wind TWG is completed. It is anticipated that the Working Group will evolve towards an implementation group, once this plan is adopted and that appropriate resources will be assigned to the administration and collation of



the reporting to the SET-plan steering committee each year for the life of the plan. Nevertheless, it needs to be discussed if this is the best framework in which to continue the positive and intensive work already carried out. The involvement and collaboration framework created among European countries in the development of the Implementation Plan for offshore wind has a great value and should be leveraged in a continued effort.



ANNEX 1 – R&I Priority Actions

Annex: Priority Action 1: System Integration

Declaration of Intent Offshore Wind

Summary: By 2030 wind energy could supply around 30% of EU's power demand [Wind Europe: Wind energy in Europe, scenarios for 2030, September 2017]. This illustrates the potential of offshore wind energy and strengthens the importance for it to be highly reliable and well-integrated into the overall energy system. System integration plays a key role in reducing overall energy costs. System integration can be divided into the following aspects:

- **Electrical infrastructure**
Design of cost effective grids and interconnections. The offshore grid to connect the wind farms are addressed as well as interconnections. The inter-array cables in the wind farms are not addressed.
- **Flexibility**
Even although offshore wind energy already proves to be a stable and highly available energy source (see study "Energiewirtschaftliche Bedeutung der Offshore-Windenergie für die Energiewende" by Fraunhofer IWES, December 2017), the design of solutions and according business models to make wind power a more flexible energy source, well integrated in the overall energy supply system is of high importance. This entails both storage and energy conversion (P2X).
This is a very broad topic which includes solutions like an energy island that could facilitate energy storage and power conversion.
- **Synergy with oil & gas sector**
The activities in oil and gas sector have resulted in a huge offshore infrastructure over time. There are many platforms and pipelines that will become obsolete within the next decades. The presence and availability of empty oil and gas fields might give opportunities for CO₂-storage, energy storage (CAES, H₂) and other. There might be opportunities to re-use this existing infrastructure (empty fields, platforms and pipelines) for energy conversion, transport and storage and thereby balancing the wind power and reducing transport costs.

State of the art: System integration has been considered as an important topic before. This has resulted in a number of activities both on international and at national level (see below)

Non-technological aspects: Mainly the differences in rules and regulations can be a barrier for system integration. This is way in the frame of the Political declaration on the North Sea support groups are working on the harmonization of rules and regulations.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets



Name North Sea Declaration	Description: The objective is to facilitate the further cost-effective deployment of offshore renewable energy, in particular wind, through voluntary cooperation, with the aim of ensuring a sustainable, secure and affordable energy supply in the North Seas countries, thereby also facilitating further interconnection between North Seas countries and – whilst focusing on a step-by-step approach – with the perspective of further integration and increased efficiency of wholesale electricity markets in the longer term, contributing to a reduction of greenhouse gas emissions and in average wholesale price spreads and to enhanced security of supply in the region.	Timeline:	Location/Party	Budget unknown
Name Innovation Program North Sea Energy	Description: In The Netherlands there is already an 'Innovation Program North Sea Energy'. This Innovation Project has clear goals focussing on gathering and developing specific knowledge on offshore system integration: 1. To increase insight into the interplay between different users and interests relevant for the strategic planning of energy activities in the North Sea domain and the associated impacts on the system and its surroundings; 2. To provide insight into the human capital agenda for the offshore sector and present the regulatory framework for offshore system integration; 3. To provide insights into the techno-economic status of potential offshore energy system integration options and assess the commercial value for the Netherlands of further developing these options; and 4. To better understand how system integration could improve the health, safety and environmental performance of the offshore energy sector as a whole. The final and foremost goal of the project is: 5. To serve as a knowledge sharing platform where stakeholders from multiple disciplines and sectors will join forces and share information, knowledge and expertise. In the program, five options for system integration between offshore wind and offshore oil and gas are being studied: electrification of platforms from wind power, power to gas, gas to wire, energy storage and carbon transport and storage.	Timeline: 2017 - 2022	Location/Party This Innovation Project has evolved into a National Innovation Program North Sea Energy under the umbrella of the Topsector Energy. It is collaboration of 20 partners of key knowledge institutes and universities, together with industry partners from the offshore oil and gas and offshore wind operators and maritime service companies, as well as governmental organisations such as TenneT and EBN. The program is linked to the North Sea Energy Coordination group consisting of NOGEPA, NWEA, Natuur & Milieu, TENNET, VNO-NCW and TNO which seeks to coordinate activities in the area of North Sea energy development (www.gasmeetswind.eu).	Budget It is a 5 year program with a budget of 1 M5/year.



Name GROW initiative	Description: "Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines. One of these is the integration of offshore wind in the energy system.	Timeline: 2017-2022	Location/Party Research groups at industry, institutes and universities within The Netherlands	Budget various projects budgets: Total >10 OM
Name 6th Energy Research Programme of the Federal Government (DE)	Description German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role. See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html	Timeline: 2011-2018 (to be followed by 7 th Energy Research Programme) (to be followed by 7 th Energy Research Programme)	Location/Party: This German national research programme is open for universities, research institutes and enterprises	Budget: 340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects
IEA Wind TCP Task 25	Several European countries are taking part in the IEA Wind TCP Task 25 "Design and Operation of Power Systems with large amount of Wind Power"			
Name NSON - North Sea Offshore and Storage Network	Description Within the NSON initiative Partners from Norway, Great Britain, Denmark, Ireland, the Netherlands and Germany collaborate in order to assess different types of grid and market connections for an offshore grid in the North Sea. The project covers topics like multi-terminal HVDC, market coupling or implementation of ancillary services.	Timeline: 2014 - 2017		Budget: Germany's funding cumulates to 2 m €



Name H2020- MUSES	The Multi-Use in European Seas (MUSES) project will look at how European seas are currently being used and what could be the real multi-uses opportunities. The Multi-Use in European Seas (MUSES) project will review existing processes, used across the EU, for marine and coastal development to ensure they are sufficient for the sustainable, multi-use of the marine environment. The project will provide Regional overviews of the EU sea basins, including: Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic. A comprehensive set of case-studies will also be conducted and analysed and an action plan will be put forward to look at how to: build on and reduce gaps in existing knowledge, identify impacts and risks and maximise local benefits while overcoming existing barriers. Multi-use combinations related to renewable energy (wind and wave) and O&G decommissioning are specifically considered in the Mediterranean and in other Sea Basins.	Timeline Nov 2016 – Oct 2017	Location/Party EU Sea Basins, including the Mediterranean	Budget 2M€
Name RITMARE (Italian Flagship Project on Marine and Maritime Research)- ICM-MSP in the Adriatic-Ionian Region	The activities of RITMARE - ICM-MSP in the Adriatic-Ionian Region aim at: - support the overall MSP implementation process in the area; - make available valuable data, tools and knowledge for the development of sound planning and management solutions; - develop site-specific ICM-MSP analysis on areas having a great concentration of uses and potential conflicts (e.g. tourism, maritime traffic (ferries, goods, passengers, leisure boats), oil&gas, renewable energy, aquaculture, fisheries, sand extraction, coastal defence, protected areas), to address planning and management measures. This ICM-MSP exercise is carried out on the Emilia-Romagna coast and marine waters and considers through specific analyses the issue of O&G decommissioning and reuse, also in connection with possible offshore wind farms.	Timeline 2016 - 2017	Location/Party Italy	Budget 220k€

Title: 1.1 Electrification of an existing gas production platform

Targets: demonstrate the electricity supply and the dynamics of this, but also possible synergies in operation and maintenance (storage of spare parts, integrated services etc.)

Description deliverable: Wind turbines could be connected to a production platform to supply the necessary electricity and to replace the fossil fuel fired gasturbines, which are bounded by more stringent emission regulations.

Electrification of platforms would not only reduce CO₂ and NO_x emissions to zero but would also reduce the use of fuel gas and reduce the operations costs

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 10 million - see Table 1 core text



Title: 1.2 Gas2Wire

Targets: Demonstration of enhanced flexibility by combining wind energy with natural gas resources

Description deliverable: Pilot demonstrating the production of electricity in existing gas fields using the electrical infrastructure of wind farms. By combining wind farms and electricity from gas2wire a flexible system will be created capable of producing electricity on demand and increasing the load factor of the power cables. The CO₂ produced by the burning of natural gas could be injected in the gas field to reduce the carbon foot print.

TRL: 6 – 9 Industrial research & demonstration

Total budget required: EUR 10 million - see Table 1 core text

Title: 1.3 Power to Gas and Hydrogen Production phase 1 & 2

Targets:

Creating	full	flexibility	in	electricity	production
Testing and optimisation of different hydrogen production methods					

Description deliverable:

Electricity produced by wind farms can be used to produce hydrogen by means of electrolysis, thus creating a more flexible system. The hydrogen can be used to produce electricity using fuel cells or other equipment when the wind farm is not producing due to a lack of wind or directly be transported to shore in existing pipelines to be used in the process industry as a fuel or feedstock. In case of local electricity production, the optimal solution for hydrogen storage will be assessed. In a demonstration project alternative technologies to produce hydrogen can be investigated and amongst others experience will be gained to decrease the costs and the footprint of this kind of installations. Also the dynamic performance of various types of electrolyzers can be evaluated.

TRL: Phase 1: TRL3 – 6; Phase 2: TRL 6 – 9

Total budget required: EUR 45 million - see Table 1 core text

Title: 1.4 Energy storage in depleted gas fields (CAES or Hydrogen) phase 1 & 2

Targets: Seasonal storage of large energy volumes

Description deliverable:

Energy storage is a dominant factor in the integration of renewable sources, playing a significant role in maintaining a robust and reliable modern electricity system. It can improve the electric system flexibility, and enables the storage and dispatching of the electricity generated by variable renewable energy sources in the sea.

Different storage technologies are used in electric power systems. They can be chemical, electrochemical, mechanical, electrical or thermal. Large volumes of energy can be stored in depleted gas fields offshore. This energy can be stored with a method which is used in onshore salt caverns, such as CAES or Hydrogen. This has not yet been implemented in depleted fields nor in an offshore environment. This can help to balance the energy system offshore and stabilize the intermittent production from wind.

TRL: Phase 1: TRL1 – 3; Phase 2: TRL 3 – 6



Total budget required: EUR 30 million - see Table 1 core text

Title: 1.5 Development of cost-effective solutions for the integration of wave and wind energy production

Targets:

- Identification of new concepts, which integrate wave and wind energy production
 - Development of numerical models for the representation and optimization of such concepts
 - Intermediate-scale field experiments for validation of the numerical models through at-sea tests.
-

Description deliverable:

The integration of different renewable energies is a road towards the increase of their efficiency and cost-effectiveness. In particular, the integration of wind and wave energy production would provide many advantages. Firstly, the sharing of the support structure and of some electric components would reduce costs. Moreover, wave energy absorption would protect the support structures, by attenuating the wave loads, and would reduce the variability of the energy production, providing energy production even in absence of significant wind, due to the swells. The aim of this Activity is to identify and test innovative concepts, based on the integration of wind and wave energy production, in order to provide reliable and cost-effective solutions to the current challenges with respect to this task.

TRL: TRL 2 (Target 1-2), TRL 5-7 (Target 3)

Total budget required: EUR 5 million - see Table 1 core text

Title: 1.6 Concept development of an artificial energy island

Targets: Feasibility study for the development of artificial floating energy islands. Islands in the North Sea and floating islands in the Mediterranean Sea.

Preliminary prototype, by re-using an O&G platform, possibly on the Adriatic sea.

Description deliverable:

The activity consists in the feasibility study and design of a preliminary concept for the energy island in an identified area of the **Mediterranean Sea**. It is a floating smart city where productive, recreational and energy production activities are integrated in a cooperative and interdisciplinary concept. From the energetic point of view, wind and solar power will be the dominant renewable energy sources, with WEC and current devices that can provide additional energy power as well as improve protection and comfort to the human activities on the island.

To the purpose, the island will be composed by two staggered external rings with WEC and current devices, with the dual function to extract energy and serve as breakwaters, inducing a mild water region in the internal part of the island. Here, platforms for solar panels and wind turbines will be installed, as well as productive (hydrogen production, desalinization plants, aquaculture) and recreational activities. The energy produced will be used locally, i.e. the island will be energetically autonomous, avoiding any grid for the energy transfer on land. Mechanical storage system will be installed in order to reduce the power fluctuations.

Feasibility studies for an energy island in the **North Sea**, connecting large offshore wind farms to shore. The island is used for collecting power from various wind farms and transmitting that efficiently to shore. Additional functionality is an installation and O&M base, space for flexibility options such as P2X etc.

TRL: Start 2 End 4-5

Total budget required: EUR 15 million - see Table 1 core text



Annex: Priority Action 2: Wind Energy Offshore Balance of Plant

Summary:

Offshore wind power has to play a crucial role in the European energy system, however the cost of offshore wind power is higher today than that of onshore, which in large part is due to the more expensive installation processes and higher associated O&M costs of working at sea. Offshore balance of plant includes the substructure and foundation, site access, offshore electrical infrastructure and assembly and installation, representing a significant proportion of costs for an offshore wind project. R&I within the balance of plant needs to focus on continued cost reduction through large-scale infrastructure for research, development and demonstration. R&I is required to optimize the design of fixed and floating foundations, as well as to help to understand the drivers for reliability of electrical infrastructure

Research gaps that have been identified to date are:

- **Offshore physics (soil damping, breaking waves, soil-structure-fluid interaction, air-sea interaction).** The limited understanding of physics phenomena and model uncertainties effecting offshore balance of plant technology prevents accurate design models and optimal cost effective designs.
- **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.
- **Provision of data for verification of design models** is key to understand model uncertainties and limitations, which will contribute to reduce safety factors. 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.
- **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.

Targets of the research activities described in these R&I Activities are:

- Develop cost-effective optimized support structures
- Improve installation and assembly methods
- Develop reliable and cost-effective electrical infrastructure for offshore wind farms
- Enable cost-effective floating wind farms

State of the art:

Non-technological aspects: One could also envisage multi-functional designs for issues such as desalination, fish farming, emergency military functions, environmental observation and territorial management.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/Party	Budget
GROW initiative	"Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines, which includes R&I on operation and maintenance of offshore wind farms.	2017-2022	Research groups at industry, institutes and universities within The Netherlands	various projects budgets : Total > 1 000 M



Name	Description	Timeline:	Location/Party:	Budget:
6th Energy Research Programme of the Federal Government (DE)	<p>German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role.</p> <p>See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html </p>	2011-2018 (to be followed by 7 th Energy Research Programme) (to be followed by 7 th Energy Research Programme)	This German national research programme is open for universities, research institutes and enterprises	340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects



Title: 2.1 Lifecycle cost optimization for Installation and Balance of Plant for deeper water wind farm sites

Targets:

- (1) Develop and implement balance of plant solutions related to deep water (>50m) deployments and operations, that will maintain the offshore wind sector competitiveness in the North Sea.
- (2) Accelerate the development of deeper water sites

Description deliverable:

Developing technological solutions and operational procedures that will overcome the challenge that deeper water, more exposed sites pose to the industry. By building EU wide standards, thus maintaining EU's global leadership in technology, Installation and balance of plant (substructures, cables, substations) represent a significant portion of the CAPEX for an offshore wind farm. Finding cost effective solutions for the more challenging North Sea sites is an important step for the industry in terms of maximizing the utilization resource and for transitioning the industry to floating technologies in Atlantic locations. The future growth of the industry into deeper waters located further from shore requires new solutions in terms of substructure design and in particular the use of integrated solutions that minimize costly marine operations and enable installation activity across broader weather windows.

Activities related to installation of offshore wind farms are among other things:

- Innovative solutions for faster and more cost effective installation of offshore wind farms
- Optimize installation activities in particular to expand weather windows and demonstration by sea trials

Activities related to improving Balance of Plant

- Float out solutions for fixed substructures - GBS, floating jackets, etc.; Development of floating substation concepts
- Investigate limitations to feasible depths and sizes for fixed foundations
- Use of new materials (composites), modular units, design innovations (telescopic towers) and assembly processes
- Fast decoupling dynamic cable connection systems and dynamic mooring systems to control motions and load reduction
- Application/development of robotic systems for monitoring and minor repair operations

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 5 million - see Table 1 core text



Title: 2.2 Understanding and modelling offshore physics for wind farm design and operation

Targets:

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

Description deliverable:

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

The interaction between soil and foundation needs further understanding. A reduction in material usage in monopile fabrication is possible. The development of better scour protection, monitoring and prevention will minimise the risk of future problems associated with the seabed surface. Reduced buffers in design standards will enhance further cost reduction.

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

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 5 million - see Table 1 core text

Title: 2.3 Experiment for open access data set for validation of design models for offshore wind farms

Targets: The creation of open access experimental databases will enable effective design model validation and uncertainty calculations, leading to faster improvements of design tools and, ultimately, more accurate designs of balance of plant as well as wind turbine technology

Description deliverable: There is a lack of open data from Offshore Balance of Plant requiring dedicated effort to create open access experimental databases.

An example is the Dutch initiative to develop an experimental facility at Hollandse Kust Noord, which is to be a field lab for experiments, demonstration and validation. The data collected at such offshore facility enable effective design model validation and uncertainty calculations, leading to faster improvements of design tools and, ultimately, more accurate designs of balance of plant as well as wind turbine technology.

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 10 million - see Table 1 core text

Budget for an experimental offshore wind energy facility is required.



Title: 2.4 Validated model chain for system engineering and multi-disciplinary optimization (floating and fixed)

Targets:

Effective coupling of offshore design models (i.e. balance of plant - wind turbine) and metocean models is needed to enable overall system optimization. Validation of the design model chain (for floating and fixed technology) is key to understand design uncertainties, which is a key driver in probabilistic design.

Description deliverable:

In terms of design, the focus should be on turbine/foundation interaction and station keeping systems by means of integrated design. Validated model chain for system engineering and multi-disciplinary optimization need to be developed including the developments of models for design and testing of anchors and mooring systems. Dynamic anchoring systems will provide more robustness to floating systems leading to cost reductions. The cables will require further investigation; R&I should develop further knowledge on the connection of inter-array cables in floating arrays, including the lifetime and optimisation of dynamic cables.

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

Improved and coupled theoretical models for this complex interaction between (fixed and floating) turbines and environment must be developed. In addition, R&I will need to move from single machine modelling to wind farm scale modelling using multiscale approach and overcome the current limitation of hydrodynamic and aerodynamic behaviour modelling using petaflop clusters.

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 5 million - see Table 1 core text

Title: 2.5 Mechanical and electrical design conditions for electrical infrastructure

Targets: 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, are required to improve reliability and cost of balance of plant technology.

Description deliverable:

Offshore electrical infrastructure has significant cost and requires special treatment. Research on offshore substations and cables can shape their future in accordance with the development of the offshore wind turbines, foundations and substructures. An important research priority are new developments and better understanding of mechanical and electrical design conditions.

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

- A better understanding of fatigue in subsea array and export cables is achieved by better understanding the interaction between the seabed and cables in relation to temperature dissipation or a moving seabed. Monitoring the cables must improve reliability and improved burial may reduce failures.
- The development of floating substations will open up new possibilities, especially for deep water areas.
- The development of HVDC and MVDC technologies or suitable alternatives (including HVDC diode rectifiers, LFAC, HVAC technologies) could ensure an efficient connection of offshore wind resources to onshore loads.

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 5 million - see Table 1 core text



Annex: Priority Action 3: Floating Offshore Wind

Main Key Action / Declaration of Intent

Summary: Floating Offshore Wind (FOW) holds the key to an inexhaustible resource potential in Europe. 80% (approximately 4000 MW) of all the offshore wind resource is located in waters 60m and deeper in European seas, where traditional bottom-fixed offshore wind is not economically attractive. Under the right conditions, FOW can be a significant driver supporting the energy transition. If Europe is to keep its global technological leadership in offshore wind, it needs to move fast to deploy floating offshore wind. IEA floating offshore wind experts suggest that there can be up to a 50% cost reduction by 2050.

One of the key advantages of FOW is that turbines will be located in areas with much higher average wind speeds, giving turbines the ability to harness the best possible wind resources without depth constraints. The capacity factor can thus be improved and lead to an increased generation of electricity. With higher capacity factors, the levelized cost of energy (LCoE) will therefore be reduced.

The significant increase in turbine sizes is another factor. Larger turbines are a good fit for FOW as they can withstand high wind-speeds and generate higher output per turbine. And also, they are much easier to integrate into floating systems since nowadays there are cranes available to install those turbines at those heights taking the most from shipyards and ports and harbours already existing infrastructures. (f.i. Hub height 140 meters, offshore wind turbine rated 12-13 MW). Moreover, larger turbines have already shown limitations in onshore sites, but in offshore sites they may provide higher economy of scale rates and therefore higher revenue rates.

Floating support structures are essential to exploit the full potential of offshore wind in the future. Reliable platforms need to be designed, tested and validated. An increase in offshore wind installations is needed in order to meet renewable electricity generation targets set by the European Commission. Technology improvements are still needed in a wide range of engineering fields prior to enhance the deployment of overall offshore wind capacity and subsequently support the EU in reaching the 2030 targets. If Europe is to keep its global technological leadership in offshore wind, it needs to move fast to deploy floating offshore wind and exploit its enormous potential and get mature an incipient industrial sector. Floating offshore wind will take advantage of cost reduction techniques developed in bottom-fixed offshore wind thanks to the significant area of overlap between these two marine renewable energy solutions. Finally, FOW platforms offer the possibility to integrate with other renewable energy devices (i.e. WEC and sea currents converters) as well as with other productive activities (e.g. aquaculture, Oil and Gas).

A clear emphasis will be given to the technological solutions to be adopted consistently with the peculiarities of the different EU offshore sites in terms of sea and wind state and water depth (North Sea, Baltic Sea, Mediterranean Sea or Atlantic Ocean).

Support platforms R&D activity can be divided into the following aspects:

- Floating concepts/platform (barge, semi-submersible, spar, TLP..).
- Mooring Systems.
- Electrical cables and interconnections, floating substations
- Logistics, Installation, Decommissioning and O&M.
- Synergy with shipbuilding sector and other related engineering sectors (i.e. concrete structures)
- Synergy between ports and harbours facilities and future floating offshore wind farms
- Creating added value.



State of the art: Support platforms have been considered as an important topic before. This allows for a more stable structure and has resulted in a number of activities both on international and at national level. There are currently four substructure designs for floating offshore wind in development: barge, semi-submersible, spar buoy and tension leg platform. The first three are loosely moored to the seabed, allowing for easier installation, while the tension leg platform is more firmly connected to the seabed. While this technology was previously confined to R&D, it has developed to such an extent that the focus is now moving into the mainstream power supply. The technology readiness level (TRL) related to semisubmersible and spar buoy substructures has entered a phase (>8) in which the technology is deemed appropriate for launch and operations. The barge and the tension leg platform (TLP) concepts are projected to reach this stage in the coming years.

Non-technological aspects: Mainly the differences in rules and regulations can be a barrier for system integration. This is way in the frame of the Political declaration on the North Sea support groups are working on the harmonization of rules and regulations.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/ Party	Budget
LIFES50+ Project. <i>QUALIFICATION OF INNOVATIVE FLOATING SUBSTRUCTURES FOR 10 MW WIND TURBINES AND WATER DEPTHS GRATER THAN 50m.</i>	The focus of the project is on floating wind turbines installed at water depths from 50m to about 200m. The consortium partners have chosen to focus on large wind turbines (in the region of 10MW), which are seen as the most effective way of reducing the Levelized Cost of Energy (LCoELCoE). The objective of the project is two-fold: Optimize and qualify, to a TRL5 level, two (2) substructure concepts for 10MW turbines. The chosen concepts are taken from an existing list of four TRL>4 candidates currently supporting turbines in the region of 5MW. The selection of the two concepts is made based on technical, economical, and industrial criteria. The DTU 10MW reference wind turbine design is used throughout the project. More generally, develop a streamlined and KPI-based methodology for the design and qualification process, focusing on technical, economical, and industrial aspects. This methodology is supported by existing numerical tools, and targeted development and experimental work. It is expected that resulting guidelines/recommended practices will facilitate innovation and competition in the industry, reduce risks, and indirectly this time, contribute to a lower LCoE End users for the project deliverables will be developers, designers and manufacturers, but also decision makers who need to evaluate a concept based on given constraints.	Jun 2015 – Oct 2018	EU / SINTEF OCEAN (NO) (Coord), DTU (DK), ORE-CATAPULT (UK), POLITECNICO DE MILANO (ITA), FUNDACION TECNALIA R&I (ES), IREC (ES), Stuttgart University (DE), IBERDROLA (ES), DT OLAV OLSEN (NO), RAMBOLL MANAGE CONSULT (DE), GL Industrial Services (DE), IDEOL (FRA), RAMBOLL II (DE)	7.3 M€



Name HYDRALAB+. TRANSNATIONAL ACCESS TO THE MAJOR AND UNIQUE EXPERIMENTAL HYDRAULIC AND HYDRODYNAMIC FACILITIES	Description: The project intends to improve the understanding of the dynamic response of SB FOWT (Spar Buoy Floating Off-shore Wind Turbines) under combined wind and wave conditions such as those in deep water. The proposed 3D model tests will be carried out at the large-scale deep water wave basin at DHI. Transnational access to facilities is offered via the EU funded MaRINET2 project.	Timeline: Funded (H2020). To be started	Location/ Party EU	Budget
Name FLOCAN 2 GRID Project. NEW PLATFORM SOLUTIONS AND INNOVATIVE TECHNOLOGIES ASSOCIATED TO POWER EVACUATION AND GRID INTEGRATION IN FLOATING OFFSHORE WIND FARMS	Description: The objective of FLOCAN2GRID Project is the development of two floating-scale technologies, as well as the energy evacuation system and the infrastructure necessary for its integration into a network in a real environment operation along with the necessary tools to define the logistics of operations associated with the life cycle of an infrastructure located in an adverse environment. Apart from the technical and economic viability analysis, this project seeks positioning the partners in a strategic sector such as the multi-megawatt wind energy production plants in medium and deep waters through the first experimental marine wind farm in Spain.	Timeline: 2015-2018	Location/ Party Canary islands. Spain / ORMAZABAL(ES), Cobra Instalaciones y Servicios (ES)(Coord), Esteyco (ES), Vicinay Sestao (ES), NEM Solutions (ES) and Nautilus Floating Solutions (ES).	Budget 8.042 k€
Name MIAMI Project DEVELOPMENT OF OFFSHORE MULTIMATERIAL STRUCTURES FOR SEVERE FATIGUE AND DURABILITY SOLICITATIONS IN MARINE APPLICATIONS	Description: The main objective of the MIAMI project is the development of a new multi-material component with high structural requirements for the offshore wind sector, thus demonstrating the advantages both technically and economically of the use of composites (plastic reinforced with carbon fiber and / or glass) in structures typically made of steel.	Timeline: 2017-2019	Location/ Party Spain / EMESA (ES) (Coord), GHENOVA (ES), FIBERGLASS (ES), GALVENTUS (ES), TEAIS (ES), AIMEN (ES)	Budget. 1.700 k€ (1.196 k€)



Name WIP10+ Project. WIND INTEGRATED PLATFORM FOR 10+MW POWER (ERANET COFUND H2020 DEMOWIND)	Description: The WIP 10+ project will demonstrate at sea sites and on a significant scale a fully integrated wind energy floating platform, Wind2Power, with two 6 MW wind turbines integrated and the capability to integrate additional functions due to its size. The objectives of this project are: <ul style="list-style-type: none"> • Provide a floating base for a high wind capacity. • Optimize operation and maintenance procedures. • Demonstrate that cost reduction is possible by acting on both capital and O&M. • Improve the management of the marine space. The specific results expected are: validation of numerical and laboratory estimates of forces and movements, engineering design test including moorings and wind platform. In a broader sense, the expected results are: survival of the platform in winter conditions in a real marine environment, quantification of cost reduction compared to two floating wind turbines, and optimization and validation of specific procedures for installation, operation and maintenance.	Timeline: 2016-2018	Location/ Party Spain / EnerOcean (ES) (Coord) - Ingeteam Service (ES) - Ghenova Ingeniería S.L. (ES) - Tension Tech International LTD (UK)	Budget 0.988 k€
Name MIUR-Teorema Project (CTN BIG)	Description TEOREMA is a joint Italian project funded by the Minister of the Research. It is performed by the National Research Council (CNR), the Italian National Agency for the New Technologies, Energy and Sustainable Economic Development (ENEA), the Politecnico di Torino, two of Italy's main national enterprises, ENEL Green Power and Fincantieri Oil & Gas, and one of the first university spin-off companies that project and test marine energy converters (Wave for Energy). TEOREMA is divided into 6 Work Packages mainly oriented to Industrial Research. Its primary objective is to define the concept for two different technologically innovative offshore platforms for energy production from wind, solar radiation, waves and MFC (Microbial Fuel Cell), also accounting for their feasibility and sustainability and implementing suitable tools for business planning. TEOREMA sustains the design and testing activities necessary for technological innovation in the field of offshore energy production, and fosters collaborations between research institutions and enterprises in order to support Italy's competitiveness and technological advancement in the sustainable use of marine resources.	Timeline: Jan 2018 – Dec 2020	Location/ Party Mediterranean Sea	Budget. 750 k€



Name H2020-BLUEMED Project	Description The BLUEMED project aims at boosting Blue Growth in the Mediterranean by promoting the concrete and operational implementation of the BLUEMED SRIA, converting its outputs into actions. This project has the privilege to set - for the first time in the whole Mediterranean Basin - the scene for the long-term effective coordination of marine and maritime research and innovation activities, consolidating networks and establishing mechanisms that will remain and be further developed after the conclusion of the project.	Timeline: Oct 2016 – Sept 2020	Location/ Party Mediterranean Countries	Budget. 3 M€
Name TKI wind op Zee (NL)	New concepts: design of new substructures. Integrated design of tower/substructure, new joining techniques, new materials	Timeline: ongoing	Location/ Party Netherlands, but open for international cooperation research institutes, universities and enterprises	Budget. Total budget of TK Wind op Zee 70 M€ (not exclusive for this topic)
Name 6th Energy Research Programme of the Federal Government (DE)	Description German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role. See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html	Timeline: 2011-2018 (to be followed by 7th Energy Research Programme) (to be followed by 7th Energy Research Programme)	Location/ Party: This German national research programme is open for universities, research institutes and enterprises	Budget: 340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects



Title: 3.1 Development of cost effective multi-MW multipurpose modular floating platforms made of concrete or steel.

Targets: Assessment of a set of new multipurpose modular floating concepts at lab or full scale for shallow, intermediate and deep water depths. These platforms would have a reduced series of common basic designs, adaptable so that different industrial plants can be installed to be exploited in marine sites.

Description deliverable:

The development of cost effective, robust, stable and simple multi-MW multipurpose modular standardized floating platforms made of concrete, steel or a combination (Hybrid) can facilitate the economic viability of this power generation technology. These platforms would have a reduced series of common basic designs, adaptable so that different industrial plants can be installed to be exploited in marine sites. In order to carry out these new platforms, platform scalability developments have to be done, new methodologies for floating wind platform testing at reduced scale are required to improve precision, validation and analysis of system dynamics are required and advanced numerical models has to be developed on hydrodynamics: second order forces, slamming forces, etc.; mooring loads performance: snap tensions; structure definition: hydroelasticity/hydrodynamics and structural mechanics coupling; advanced wind turbine modelling and integration solutions, validation of computer models of waves behaviour and subsequent structural load, wind turbine control system integration in floating offshore wind platform design, load and dynamics validation of WTG on floating prototypes. Finally, the use of dynamic cable requires of specific analysis like the influence over floating platform dynamics, adapted architectures, lay-out operations and stress calculations. Phase 1: Concept development of cost effective multi-MW modular floating platforms made of concrete or steel. Phase 2: Development of cost effective multi-MW modular floating platforms made of concrete or steel.

Phase 1: **TRL:** 2 – 6 Fundamental research & Industrial research

Phase 2: **TRL:** 6 – 9 Industrial research, Demonstration / Innovation & market uptake

Total budget required: EUR 170 million - see Table 1 core text

Title: 3.2 Improvement of manufacturing procedures and standardization of floating platforms.

Targets: Development of Innovative manufacturing, assembly, transport, installation and decommissioning processes and standards for multi-megawatt floating foundations.

Description deliverable: Floating substructures have higher potential for standardization than bottom fixed (not very sensitive to water depth and soil conditions). Efficient and cost effective mass fabrication of floating substructures has to be prioritised. For this reason an specific industrialization plan is required including lean manufacturing strategies to reduce the cost of floating technologies.

Launch of a coordinated action involving marine authorities, certification bodies and key industry players to ensure that design standards developed for floating structures are wind specific and not merely a transfer of oil & gas methodologies. Designs that can be modular and manufactured in a dock, on a barge or on a quay are very recommended. Attention should focus also on inspection processes and non-destructive testing (NDT), since they can increase costs significantly. Marine operations will be widely reproduced at the sea, therefore standardized procedures need to be developed towards an efficient and safety FOW farm exploitation. Key marine operations involved on representative O&M of a FOW farm will be modeled in order to evaluate the met-ocean conditions influence over the potential standardization of FOW farms.

Phase 1: **TRL:** 2 – 6 Fundamental research & Industrial research

Phase 2: **TRL:** 6 – 9 Industrial research, Demonstration / Innovation & market uptake

Total budget required: EUR 60 million - see Table 1 core text



Title: 3.3 Development of advanced mooring systems

Targets:

- Use of advanced mooring systems and active sensors.
 - Development of specific cost effective mooring solution for offshore.
 - Development of shallow, intermediate, deep and very deep mooring systems. The anchoring challenge at ultra deep waters: Soil–anchor interaction. Analysis and integration of new materials.
 - Use of underwater monitoring systems to ensure mooring system's integrity, and associated underwater data communication technology.
 - Definition of proper Mooring Integrity Management Policies throughout the lifecycle of the mooring systems (design, manufacturing, installation, operation & maintenance and decommissioning) with the target to reduce LCoE, while ensuring system's reliability throughout the lifetime.
 - Innovative mooring concepts and mooring components to facilitate installation, connection/disconnection of moorings and floaters, and reduce associated costs
 - Testing mooring in order to develop solutions that can be tested at reduced cost.
 - Development of innovative solution for the umbilical cable layout, associated to new mooring systems configurations
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Description deliverable:

Floating offshore wind turbine structures are held in position by means of mooring systems which, depending on the type of the structure and the water depth where it is to be moored, can have different levels of complexity. For floating wind turbine applications, a general distinction must be made between slack catenary, taut catenary, and taut tension leg mooring systems. In slack catenary designs, the lower part of the line often rests on the seabed, which adds more complexity to the system. In the oil and gas industry, large floating drilling platforms are restored by up to 20 mooring lines with different geometrical and material properties. The lines consist of a combination of chains and cables made of natural or synthetic fibers (e.g., polyester, aramid, polyamide, polypropylene fibers). Submerged buoyancy tanks located along the mooring lines also are common. Such complex mooring solutions likely will be implemented and specially adapted for future floating wind turbines as well, thus requiring the codes to have adequate capabilities. In addition to station-keeping, the mooring system also provides stability. For some platform designs, such as the tension-leg platform (TLP), the mooring system is the main contributor to the system's stability—meaning that a failure in this component would likely cause the destruction of the complete system. The mooring system of floating wind turbine platforms therefore is one of the most important components for the stability and the dynamic behaviour of floating offshore wind turbines, making appropriate modelling of the mooring system highly critical during the design process. Floating wind turbines are sophisticated structures that are subjected to simultaneous wind and wave actions. The adequate development of shallow, intermediate, deep and very deep mooring system presents several challenges that need to be solved as dynamics effects depending on the water depth, anchoring at very deep or ultradeep waters, including soil–anchor interaction and the possibility to integrate new materials, advanced monitoring solutions and others

Phase 1: **TRL: 2 – 6** Fundamental research & Industrial research

Phase 2: **TRL: 6 – 9** Industrial research, Demonstration / Innovation & market uptake

Total budget required: EUR 60 million - see Table 1 core text



Title: 3.4 Integrated floating offshore platforms –Engineering tools development & validation

Targets:

- Development of enhanced system engineering models as for example efficient nonlinear numerical models for support structures of floating wind turbines.
- Development of a certified experimental database for floating wind turbines for laboratory testing : operational and survivability tests.
- Development of experimental tests on the identified model prototypes in natural lab for
 - Identification of the model dynamic properties in relevant environment;
 - Validation of numerical models and of the laboratory testing at larger scale with field experiments.
 - Collection of large database on support structure motions and loads, to be used in long-term analysis.

Description deliverable:

The main activities in the non-linear modelling will be developed over three different levels: (1) wave modelling, aiming at increasing the complexity of models for incoming waves (e.g. nonlinear models until breaking event), which are merely considered linear in most of the common ocean engineering practices, due to different relative wave-structure dimensions, (2) large motion prediction require research effort since the majority of the theory break down (e.g. linear radiation and diffraction) and very few attempts have been developed (e.g. Fluid-Impulse Theory and Weak-Scattering Theory) for this condition so far, (3) mooring line models, to capture the non-linear behaviour of mooring line systems such as catenaries and tension legs for novel advanced concepts of floaters.

Model testing is a key aspect for the qualification of innovative floating wind turbine concepts: it is the only way of mitigating the risk related to assumptions inherent to numerical modelling. Wind tunnels are the best place to validate aerodynamic properties of designs since they offer controlled conditions for the wind profile, turbulence intensity distribution and integral scale length. The following issues appear when considering wind turbines mounted on floating structures: wave induced motions of the turbine have consequences on the relative flow field and generate aeroelastic effects, Froude scaling (water waves) and Reynolds scaling (aerodynamics) laws enter in conflict, and consequently full-scale blades aerodynamic properties cannot be reproduced at the very low Reynolds level associated to Froude scaling in the water tank. Whilst model tests in a wave tank are a must for qualifying any floating structure under realistic wave and current weather conditions, the quality of wind modelling in wave tanks will never reach that of wind tunnels, and the same problems are faced again in wave tanks regarding the actual aerodynamics of Froude scaled blades. The two experimental lab types are complementary and the whole system must be tested in both the environments.

Finally the experimental tests conducted in a natural lab is the assessment of the support structure behaviour in relevant environment and at relatively large scale (up to 1:10). With respect to the indoor testing, with intermediate scale field experiments several important aspects of the structure dynamics can be more properly investigated. The coupling between the support structure, the mooring system and the wind turbine will be more representative of the full-scale conditions, thanks to the reduction of scale effects due to the larger size of the model. Fully three-dimensional irregular waves are naturally available and large arrays of structures and sensors can be deployed, to investigate 3D effects, especially for supports with large water-plane area. Long-term phenomena such as fatigue can be investigated, thanks to the greater duration of the experiment. Wind turbine-floating platform interaction it is highly dependent on wind turbine control system, as well as on platform dynamics. Numerical models are a crucial tool for exploring standardized control systems for floating platforms, however they need to be calibrated and validated based on experiments. Because of that, by means of hybrid testing methods experimental evidences about floating platform and wind turbine coupling will be explored. Based on them an experimental data set need to be created focused on numerical modelling improvements.

TRL: 5 – 6 Industrial research & demonstration

Total budget required: EUR 2 million - see Table 1 core text



Title: 3.5 Comparative study of different support structures for floating wind turbines for specific EU sites (Mediterranean Sea, Atlantic Ocean).

Targets:

Comparative study of different support structures for floating wind turbines for specific EU sites (Mediterranean Sea, Atlantic Ocean).

Description deliverable:

Define floating substructure concepts to a 10MW/15MW wind turbine for water depths from 100 m to 300m, typical for the Mediterranean Sea and other EU sites, is the main target of this R&I activity. To fulfill this target, it is necessary to define a design basis for the substructure, including the selected locations and the reference wind turbine. The floating substructure concept must be numerically characterized by using the numerical models and concepts must be evaluated based on a clear procedure and on very detailed concise parameters, among them LCoE is the key one. The experience of the EU funded project LIFES50+ should be a very good starting point for this topic. The comparison procedure needs a multi criteria tool that permits to choose among different designs, keeping into account the main feature of each one. In particular, within these R&I activities, engineering tools must be developed to evaluate the economical point of view (LCoE), the environmental consequences (Life Cycle Assessment) and an overall assessment of the Risks.

The LCoE calculation will be based on general assumptions equal for all the designs, those will include life cycle cost of floating wind farms and the energy production calculation, with their own uncertainty. The LCA analysis will include the global warming potential, Non-fossil abiotic depletion potential and the primary energy consumption. The evaluation criteria and methodology itself will be a very important output from this R&I activity because it will be very useful for stakeholders and inventors to have a widely used and accepted instrument to evaluate the financial investments.

TRL: 7 – 8 Industrial research, Demonstration / Innovation & market uptake

Total budget required: EUR 1 million - see Table 1 core text



Annex: Priority Action 4: Wind Energy Operation and Maintenance

Summary: For further cost reduction in offshore wind power, operation and maintenance must be optimised. The abundance of data and information of the many operational wind farms should be used in advanced analyses to improve wind farm technology. Wind energy operators should continue to make better analyses and use them to improve the design of machines, components and servicing systems.

Research gaps that have been identified are

- **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.
- **Accurate reliability models of components as functions of operation and loads**
Condition based maintenance or replacement of components relies on accurate reliability models that can predict remaining lifetime or probability of failure for a given load history.
- **Data analytics for O&M purpose**
Abundant information and data are available from wind farms, for which processing by big-data analytics technology needs to be developed.
- **Lifetime health prediction**
The potential synthesis of degradation modelling and big data analytics has not yet been accomplished to describe the lifetime consumption of (sub)components.
- **Safety**
The potential to use unmanned/autonomous underwater or surface vehicles to be used, robotics to be applied reduces the intervention with humans under hazardous conditions.

Targets of the research activities described in these R&I Activities are

- Improved plant monitoring and control for higher yield/O&M-cost ratio
- New sensor systems and data analytics for performance measurement and condition monitoring
- Increase/extend the lifetime of turbines

State of the art: A strong development is ongoing in the field of O&M. However, the operators of offshore wind farms see large potential for further cost reduction of O&M. In the market with decreasing electricity revenue, the costs for operation and maintenance much drop significantly.

Non-technological aspects: Health and Safety is of the utmost importance and is a driver for large parts of the research activities.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/Party	Budget
GROW initiative	"Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines, which includes R&I on operation and maintenance of offshore wind farms.	2017-2022	Research groups at industry, institutes and universities within The Netherlands	various projects budgets: Total >100M



Name	Description	Timeline	Location/Party:	Budget:
6th Energy Research Programme of the Federal Government (DE)	<p>German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role.</p> <p>See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html</p>	2011-2018 (to be followed by 7th Energy Research Programme) (to be followed by 7th Energy Research Programme)	This German national research programme is open for universities, research institutes and enterprises	340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects

Title: 4.1 Sensors and data analytics for health monitoring

Targets: Development of robust, reliable, accurate and durable sensors to monitor the condition and degradation of the most critical components and external conditions against lowest costs.

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

- Sensor reliability must improve through research into increased protection and redundancy, which should be considered as a parallel solution. Operational solutions such as self-diagnostic systems and multi-sensor constructions also deserve further investigation.
- Costs of sensors systems need to decrease through optimisation of the sensor suite implemented in wind energy systems. Identification of required sensors, intelligent use of cross-over data through smart algorithms must make the systems cost effective.

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 4 million - see Table 1 core text



Title: 4.2 Sensor system for performance measurements and condition monitoring

Targets: Development of reliable systems for monitoring during turbine lifetime, among others self-diagnostic systems and multi-sensor constructions. Such sensors may include remote sensing of external conditions and damage such as lidars, drones etc.

Description deliverable:

Reliable systems are developed for monitoring during turbine lifetime, among others self-diagnostic systems and multi-sensor constructions. Such sensors may include remote sensing of external conditions and damage such as lidars, drones etc.

- Wind energy R&I will need to develop new enhanced sensors for condition monitoring.
 - Further improvements in the use of remote inspection will balance the trade-offs between the use of condition monitoring systems, remote operated vehicles, drones or human inspection of wind turbines for maintenance purposes.
 - The development of new sensors for external conditions integrated within the control systems is fundamental to taking advantage of the close environment of the turbine for improved energy yields and failure prediction, in a cost-efficient way.
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TRL: 2 – 5 Fundamental research, Industrial research & lab-scale demonstration

Total budget required: EUR 10 million - see Table 1 core text

Title: 4.3 Enable digital transformation in wind energy system O&M

Targets: 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.

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

TRL: 2 – 5 Fundamental research, Industrial research & lab-scale demonstration

Total budget required: EUR 10 million - see Table 1 core text



Title: 4.4 Development and validation of models of component and structural damage and degradation as functions of loads and environment

Targets: Develop the fundamentals and results of damage and degradation from micro-scale to macro-scale level. Extensive testing programmes will validate the results.

Description deliverable:

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

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

TRL: 2 – 5 Fundamental research, Industrial research & lab-scale demonstration

Total budget required: EUR 4 million - see Table 1 core text

Title: 4.5 Use of unmanned or autonomous vehicles (in air or underwater) and the use of robotics

Targets: Improve safety of offshore operation and maintenance by replacing humans by robots and autonomous vehicles.

Description deliverable:

Autonomous Robotics: extension of a ship with a fleet of ASV/AUV cooperating between them and with the ship in order to make easier new missions for sea monitoring and offshore marine operations.

New generation of autonomous vehicles, surface and underwater, as supporting systems for maintenance and installation of the wind turbine support structure and mooring lines.

Nacelle robotics: replacing human intervention and repair actions in the nacelle by robots.

TRL: 2 – 5 Fundamental research, Industrial research & lab-scale demonstration

Total budget required: EUR 15 million - see Table 1 core text



Annex: Priority Action 5: Wind Energy Industrialisation

Summary: Industrialization is a key enabler to reduce the cost of wind energy. It represents a natural step that the wind sector has to take in order to achieve economies of scale and better cooperation along the entire value chain. The level of standardization of other industries has not been reached yet. The provision of standardized project solutions, methods, design criteria and component along the entire value chain are typical elements, which need to be facilitated by research.

Research gaps that have been identified are

- **Site assessment uncertainty;** The lack of a systematically validated model chain for site assessment causes uncertainty in project assumption and prevents common concepts for different projects.
- **Methods for assessment of system and component reliability;** Lack of recognized methods for assessment of system and component reliability when introducing new materials and technologies hampers development and standardised solutions.
- **Efficient multidisciplinary optimization methods and system engineering tools;** Tools for balancing the requirements to components and deliverables from the entire value chain using multidisciplinary optimization and system engineering and enhancing the standardisation of components and technologies are not available.

Targets of the research activities described in these R&I Activities are

- Develop standardized design criteria and interfaces for components in order to develop and harmonize the value chain
- Develop standardized methods for test and validation of systems and components
- System engineering and optimization methods

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

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

Ongoing **R&I** **Activities**
Note: collaboration in this field is initiated in IEA Wind TCP Task 37 "Wind Energy Systems Engineering: Integrated RD&D".

Name	Description:	Timeline:	Location/Party	Budget
IEC technical working groups	Standardisation is taken up by the IEC where standards are developed to assist industry and improve quality and safety. The necessary research activities to support standardisation activities have been performed at industry research groups as well as in academia. The latter research groups at institutes and universities have collected and combined the results of numerous national and international research projects, often executed in close collaboration with industry.	1990-2025	Research groups at industry, institutes and universities.	various projects budgets: Total>60M€
GROW initiative	"Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines, which includes the standardization and industrialization of offshore wind energy.	2017-2022	Research groups at industry, institutes and universities within The Netherlands	various projects budgets: Total>100M



Name	Description	Timeline:	Location/Party:	Budget:
6th Energy Research Programme of the Federal Government (DE)	German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role. See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html	2011-2018 (to be followed by 7th Energy Research Programme) (to be followed by 7th Energy Research Programme)	This German national research programme is open for universities, research institutes and enterprises	340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects

Title: 5.1 Standardised methods for quantification of site and system conditions

Targets: develop standardised methods for the quantification of and system conditions to reduce uncertainties in wind farm development

Description deliverable:

Uncertainties in acquiring site and system conditions for project planning and design are a bottleneck in development of wind farms. Standardised methods for the acquisition of site and system data need to be investigated and developed and standardised methods for the data processing chain need to be investigated and developed. The developed methods require systematical validation. It is crucial to develop a standardised and systematically validated model chain for site assessment.

Active participating at the working groups within IEC-61400 where on the base of simulation tools, specific actions must be taken in order to guarantee the safety of the system and its survivability at extreme events. In order to reach all these goals activities connected to both experimental and numerical investigations are necessary to build up a database which will represent the basis for writing guidelines, standards and certification rules.

TRL: 4 – 7: Industrial research

Total budget required: EUR 20 million - see Table 1 core text



Title: 5.2 Numerical and test methods for accurate assessment of system and component reliability

Targets:

- Development of efficient and accurate methods to assess the reliability of components and systems when introducing new materials and technologies.
- Testing and validation methods for components shall be developed and proposed for international standardisation.

Description deliverable:

The introduction of new materials and technologies in wind energy systems is mostly validated through full-scale testing of wind turbines. While other industries have developed procedures and standards that allow certification of components, in wind energy the certification is mostly performed on full-scale wind turbine testing. This hinders the introduction of new materials, new components and new technologies.

Efficient and accurate methods to assess the reliability of components and systems when introducing new materials and technologies shall be developed in order to further develop standardisation and interaction across the value chain. Concerning materials and components of wind turbines, harmonisation need take place at the certification level, providing simpler and more uniform requirements. Design codes and standards can also apply to materials in order to help the industry work on similar quality levels.

Testing and validation methods for components shall be developed and proposed for international standardization.

TRL: 2 – 7: Industrial research

Total budget required: EUR 10 million - see Table 1 core text

Title: 5.3 Validated model chain for system engineering and multi-disciplinary optimization

Targets: Development, maturing and validation of efficient models for system engineering and multi-disciplinary optimizations. The models shall be used to harmonise and standardise design requirements and allow system solutions based on modularisation and standardised components and technologies.

Description deliverable: In the extremely fast development of wind energy technology, the system engineering approach is not always implemented through the many disciplines required to design, manufacture, install and operation (offshore) wind farms. There is still huge untapped potential for further improvements in efficiency and performance by system engineering and multi-disciplinary optimization.

Validated model chain for system engineering and multi-disciplinary optimization: Efficient models for system engineering and multi-disciplinary optimizations shall be developed/matured and validated. The models shall be used to harmonise and standardise design requirements and allow system solutions based on modularisation and standardised components and technologies.

Experimental validation: Experimental activities need to be performed on various scales to ensure available data for validation. Experiments are performed in laboratories (wind tunnels, wave tanks, material characterization labs, corrosion labs), in natural laboratories at intermediate scale as well as in full-scale field labs. Experiments in laboratories are well conditioned; natural laboratories overcome some of the limitations typical of indoor testing. With respect to the environmental loads, the natural environment is representative of the real load conditions of the offshore wind turbines, including fully tridimensional irregular waves, turbulent wind and so on. Experiments on full-scale field labs may be turbine based or wind farm based.

Design of appropriate test cases for different floating wind turbine types to build up a data base of experimental results (to be kept blinded) to be used to improve the reliability of numerical codes used to predict loads on different floating platforms. This will support to write certification rules for floating offshore wind turbines

TRL: 2 – 4: fundamental research & Industrial research

Total budget required: EUR 10 million - see Table 1 core text



Title: 5.4 Design for manufacturing, construction and decommissioning

Targets:

- Development of design tools and appropriate methods that takes into account the constraints and tolerances/variability from the manufacturing and construction.
 - Identification of opportunities arising from additive manufacturing, new materials and digitalization.
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Description deliverable:

Design tools and appropriate methods that takes into account the constraints and tolerances/variability from the manufacturing and construction need to be developed. Also, opportunities arising from additive manufacturing, new materials and digitalization need to be considered.

- R&I should focus on **improved new materials** such as steel, concrete, hybrid materials (glass/carbon – concrete), self healing materials, composite structures -including new forms of glass, conductors, high stress control electronics, welding technology, transport and erection technologies in order to find a right balance between lighter, cheaper, and stronger materials.
 - The **digitisation of the wind energy sector** will trigger new communication interfaces between the different stakeholders of the value chain and the turbines. R&I should focus on how to organise this process in order to ensure that these interfaces transmit a standardised language.
 - At the manufacturing level, **common wind industry standards need to be defined on quality requirements, surface treatment, welding and cable terminations** in order to favour better interactions between factories and develop understanding and approaches to manufacturing and repairing processes. **Testing and validation methods** (e.g. blade quality, and subsystems) can provide an identical basis for quality inspection. The definition of optimised safety factors for serial production could simplify safety codes and avoid over-engineering of components.
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TRL: 2 – 7: Fundamental research & Industrial research / demonstration

Total budget required: EUR 15 million - see Table 1 core text



Annex: Priority Action 6 Wind Turbine Technology

Main Key Action / Declaration of Intent

Summary: 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 beyond its activities of today and tomorrow.

Research gaps that have been identified to date are:

- **Wind physics**
Large unknowns and uncertainties exist in the physics that underpins the design tools for wind energy, such as multi-scale flows, wakes, aerodynamics and aero-elastics, aero-acoustics, degradation of materials, electro-mechanical interaction
- **Opportunities and consequences of digitalisation**
The use of digital twin concepts or artificial intelligence to further optimise wind systems needs to be investigated and concepts developed.
- **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.
- **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, market and public. Tools needs to be developed and matured.
- **Access to and data from a wind farm 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 innovations in the certification and testing methodologies such as scaled testing and testing of components.

Targets of the research activities described in these R&I Activities are:

- Create opportunities for upscaling, breakthroughs and game changers
- Full understanding and prediction of wind energy physics (wind energy science)
- Smart turbines, applying intelligent materials, big data and AI, flow control and grid support
- Reduce risk in wind turbine design and operation
- Improvements in test and validation methods

State of the art: The development of wind energy is regarded as significant in the last decade. However, the implementation of wind energy must be 50 times larger than today for a sustainable energy system. Break-through technology is required to realise that. Break-through technology requires technology innovation as well as improved understanding of physics, digitisation and optimisation.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/Party	Budget
GROW initiative	"Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines, which includes R&I on operation and maintenance of offshore wind farms.	2017-2022	Research groups at industry, institutes and universities within The Netherlands	various projects budgets: Total>100M



Name	Description	Timeline	Location/Party:	Budget:
6th Energy Research Programme of the Federal Government (DE)	<p>German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role.</p> <p>See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html </p>	2011-2018 (to be followed by 7th Energy Research Programme) (to be followed by 7th Energy Research Programme).....	This German national research programme is open for universities, research institutes and enterprises	340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects



Title: 6.1 Disruptive technologies

Targets:

Investigate game changers and new technology solutions in rotor, drive train, support structures and electrical system while keeping a close watch on technology developments in other disciplines.

Description deliverable:

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

Demonstration of next generation offshore wind turbines suitable for the Mediterranean Sea, Atlantic ocean, North Sea and Baltic sea. The classical up scaling procedure will be replaced by a modern MDAO approach where a multidisciplinary design optimization will be driven by the peculiarities of the specific location with its wind conditions, wave state and water depth.

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 15 million - see Table 1 core text

Title: 6.2 Next generation test and validation methods

Targets:

Development of external condition measurement methods, alternatives to full-scale blade testing, test benches for drive train testing, tailor-made wind tunnel models and improvements in material testing.

Description deliverable:

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

Current needs to demands investigation on **the development of novel measurement techniques and experimental tests** that will deal with an increasing complexity, notably due to the growing size of rotors. **New methodologies for the validation** of these tests can be developed, and will pave the way for more reliable and efficient wind energy production.

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

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 10 million - see Table 1 core text



Title: 6.3 Optimized structures using innovative materials

Targets:

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

Description deliverable:

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

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

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

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

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 20 million - see Table 1 core text

Title: 6.4 Wind farm control

Targets: Investigating supervisory control of wind farms to prove the yield of the wind farm, to reduce O&M and to make the wind farm grid friendly by providing ancillary services.

Description deliverable:

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

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

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

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

TRL: 3 – 7: fundamental research & Industrial research / demonstration in field tests

Total budget required: EUR 10 million - see Table 1 core text



Title: 6.5 Demonstration of large scale turbines > 10 MW

Targets: Demonstration and testing of wind turbines larger than 10 MW

Description deliverable:

The development and testing of large wind turbines becomes increasingly more costly. Several hundred million euros is not uncommon. The development and testing is traditionally done in a serial approach. Although it is well known that physics is rather different for large turbines and the engineering design tools are used outside the validated application ranges, the testing and demonstration is mostly performed at full-scale. Component testing and parallel testing is under development and may assist the further cost reduction in the industry. Demonstration and testing of large turbines is crucial and the feedback towards engineering design tools is more urgent than ever.

TRL: 6 – 9 : demonstration in field tests

Total budget required: EUR 200 million - see Table 1 core text

Title: 6.6 Development and Demonstration of turbines larger than 15 MW

Targets: demonstration and testing turbines bigger than 15 MW

Description deliverable:

The development of turbines larger than 15MW require innovations in design, in component testing and in full-scale testing. Barriers have to be broken and innovations in design, control, materials and testing be applied.

TRL: 6 – 9: demonstration in field tests

Total budget required: EUR 150 million - see Table 1 core text



Annex: Priority Action 7: Basic Wind Energy Sciences

Main Key Action / Declaration of Intent

Summary: By 2030 wind energy could supply around 30% of EU's power demand [Wind Europe: Wind energy in Europe, scenarios for 2030, September 2017]. This illustrates the potential of offshore wind energy. The industry has recognized significant requirements to improve and develop wind turbine and wind farm technology. The enormous implementation requires the design and development of large, efficient wind turbines and wind farms to be developed in areas with more complex sites and more extreme climate.

Research in the basic wind energy sciences is required to develop the research competences and the underpinning scientific knowledge. Scientific models and data are needed for complex sites and extreme climate, larger and lighter turbines, and large-scale penetration in the energy system.

Research gaps that are identified are:

- **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.
- **Climate change and extreme climate** effect the design, performance and operation, and the development in critical geo-physical condition in the future needs to be modelled and assessed
- **System engineering models, including detailed fluid-structure, soil-structure and electro-mechanical interaction** need development in order to allow optimal design and operation for reduced LCoE and system compliance
- **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 with their degradation and failure mechanisms** provide new opportunities for weight and cost reductions, higher reliability and improved manufacture of blades, structures, mechanical and electrical components

State of the art: Over the last decades, research in underlying basic wind energy has been beneficial and essential for the development of wind energy towards the technology levels of today. There are several topics in which the industry finds continuous challenges because of upscaling wind turbines, exploring more extreme conditions and by pushing technology limits to the maximum in search for cost reductions. This has resulted in a number of activities both on international and at national level (see below) in atmospheric science, in system engineering, in material science, in controller technology, aerodynamics, structural dynamics, etc. The industry recognizes that further developments are required for the design of 10+MW wind turbines.

Non-technological aspects: Acceptance and public perception is a growing concern for the impressive implementation plans that the EU has for the development of wind power. Basic science in non-technological aspects are just as important as the technology aspects.

Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets



Name	Description:	Timeline:	Location/Party	Budget
EERA EU projects like UPWIND, AVATAR, INNWIND, RELIAWIND NEWA	<p>In the last 8 years EERA Joint Programme on Wind Energy has been running several projects aiming to better understand the physics related to wind energy and to improve the accuracy of design tools.</p> <p>UPWIND (40M€) aimed to determine limitations for the design and operation of 20MW wind turbines, where several fields of physics were investigated to improve the understanding for large wind turbines</p> <p>INNWIND (12M€) aimed to develop innovations required for the design and operation of 12MW wind turbines. Innovations were developed related to rotors, drive train, support structure and reliability.</p> <p>AVATAR (6M€) aimed to develop design tools for the design of 100m+ slender blades required for the 12+MW wind turbines. The high Reynold Number aerodynamics was also explored with improved understanding of aero-structure interactions.</p> <p>NEWA (13 M€) is ERANET + project. Aiming at producing tools for the next generation Wind Atlas for Europe. New models and experiments for validation including a detailed 200 m resolution wind atlas for Europe is anticipated as the outcome.</p>	2017 - 2022	EERA partners consist of the larger research groups in wind energy in Europe. Partners in these projects are a.o. DTU, ECN, Fraunhofer, Forwind, SINTEF, CENER, CRES, Delft University of Technology, ORE Catapult, etc.	various projects budgets: Total>70 M€
Name	Description:	Timeline:	Location/Party	Budget
GROW initiative	<p>"Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines, which includes the integration of offshore wind in the energy system.</p>	2017-2022	Research groups at industry, institutes and universities within The Netherlands	various projects budgets: Total>100 M
Name	Description	Timeline:	Location/Party:	Budget:
6th Energy Research Programme of the Federal Government (DE)	<p>German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role.</p> <p>See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html </p>	2011-2018 (to be followed by 7 th Energy Research Programme) (to be followed by 7 th Energy Research Programme)	This German national research programme is open for universities, research institutes and enterprises	340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects



Name NORCOWE	The NORCOWE programmes that was executed by the Norwegian institutes had a strong focus on wind conditions and measurement techniques for visualization and understanding of the complex wind flows. Many PhD student have contributed to the development of basic wind energy science in the fields of aerodynamics, structural design, material research and digitalization and data analyses.			
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Title: 7.1 Offshore Measurement Platforms

Targets: Measurement of wind conditions, meteorological conditions and climatological conditions on the North Sea, the Atlantic Sea and in Mediterranean.

Description deliverable: Knowledge of wind conditions offshore up to larger heights is essential for the development of the future large turbines and large wind farms. Wind power forecasts require good weather models, which on their turn require accurate measurements for better results. Long-term monitoring the wind conditions while large wind farms are operated on the North Sea is essential for the understanding the effect of wind farms on the weather. In addition, the Atlantic and the Mediterranean are seas with large untapped potential.

On the North Sea several oil and gas platforms are equipped with meteorological measurement devices. These measurements are used as input in weather models giving reliable weather forecasts. Not only this is important for air traffic, agriculture, transport and the society as a whole, it is also essential for integrating the offshore wind power in the national power systems. These platforms are being removed, leaving large concerns.

1. In this task, five to ten oil and gas platforms in the North Sea (UK, NL, D, DK, N) that are being abandoned are cleaned, topside removed and equipped with long-term measurement devices to feed the weather models of the European weather institutes.
2. In this task, a dedicated meteorological station for long-term measurements is realised as an international effort. The meteorological mast is long-term (30-year commitment) so that climatological effects can be measured without the disturbance from human intervention. The measurements up to high attitudes measure wind conditions so that the impact of wind farms on the wind conditions can be determined. The station is also very important for the monitoring of gasses, pollution and world-temperature.

In the Atlantic and Mediterranean development and updates of wind atlases is important. For that reason measurements need to be performed in coastal areas and further at sea.

1. Accurate analysis of medium term (at least 5 years) wind series profiles (10-300 m), measures with state of art wind-lidar technology, is performed to obtaining complete characterization on the base of coastal observation in complex coastal terrains. A high precision atmospheric model will be validated.
2. Data will be integrated with actual wind product of Sentinel Copernicus mission to be comparable to NEWA output for Mediterranean area results and eventually useful campaigns in other port area and on top of existing oil and gas platforms.

TRL: 2 – 4: fundamental research & Industrial research

Total budget required: EUR 15 million - see Table 1 core text



Title: 7.2 Multi-scale flow modelling

Targets: Develop the multi-scale flow physics that include the large-scale weather structures, the wind flows in wind farms, the wind flow around wind turbines that are coupled via control strategy to improve output of overall wind farms. These multi-scale flows need to be part of the integral design and operation of wind farms to improve performance.

Description deliverable: Multi-scale modelling using high fidelity and high performance computing is developed in order 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. This understanding becomes paramount with the ever expanding rotor sizes.

The required modelling efforts ranges from very large scale (weather structures) to intermediate scale (the wind flows in wind farms and the wind flow around wind turbines) to smaller scale turbulence that determines performance and loading of wind turbines. These multi-scale flow physics needs to be included in the optimisation of wind farm design which is based on integral design. Furthermore the performance of operational wind farms is improved by implementing control on several levels: turbine and wind farm.

The large diversity of scales makes the challenge larger; it requires high-fidelity modelling and high performance computing to levels not yet possible. Not only numerical mathematics models need to be developed, but the underlying physics need to be better described and high-performance computing requires powerful computer systems.

TRL: 2 – 4: fundamental research & Industrial research

Total budget required: EUR 15 million - see Table 1 core text

Title: 7.3 Integrated system-engineering tools

Targets: Development of system engineering models, including detailed fluid-structure, soil-structure and electro-mechanical interaction in order to allow optimal design and operation for reduced LCoE and system compliance.

Description deliverable: Global system models provide insights in critical interaction between system components and 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.

TRL: 2 – 5 Fundamental research, Industrial research & lab-scale demonstration

Total budget required: EUR 15 million - see Table 1 core text



Title: 7.4 Digitalization and data analytics

Targets:

Development of new sensors, data processing, machine learning and data analytics methods for implementation in data-driven design, digital twins and control and monitoring for O&M. These developments increase reliability and reduced costs in wind energy.

Description deliverable:

Wind farms are complex systems to operate and the pressure to increase performance is large. The potential of **high performance computing and digitalization** is a promising area that has not been applied to its full extent in the wind energy industry. It is urgent to initiate extensive research and testing on digitalization and data analytics. The concepts of data-driven design, digital twins, Internet of Things, improved monitoring, better sensors, improved control strategies and smart algorithms need to be developed in order realise the full potential of digitalization, and enable accurate and reliable solutions.

The use of measurement of the near-turbine wind field for improved energy yields and failure prediction can be a cost-efficient way to develop the large wind turbines. **New sensors** are developed for measuring external conditions and are integrated within the control systems of the wind turbine. Full-scale testing is part of the activities.

There is a lack of public domain experimental datasets for research and validation purposes. Dedicated experiments need to be performed in collaboration among different countries that deliver **open-access data bases**.

TRL 2 – 7: Advanced research /Industrial research & demonstration / Innovation & market uptake.

Total budget required: EUR 25 million - see Table 1 core text

Title: 7.5 Materials science

Targets: Better understanding of properties of new and innovative materials and their degradation and failure mechanisms leading to the development of new and improved materials.

Description

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 blades, structures, mechanical and electrical components. Development of new materials or treatments offer less conservative and more reliable designs needed for rotor upscaling and lifetime extension. Material science directed towards composite blades, structural elements, corrosive and erosive environment, mechanical and electrical components including generators and magnets is needed for incremental and disruptive innovations.

deliverable:

TRL 2—5: Advanced research /Industrial research & lab-scale demonstration.

Total budget required: EUR 20 million - see Table 1 core text



Annex: Priority Action 8: Ecosystem and social impact

Main Key Action / Declaration of Intent

Summary: By 2030 the offshore wind capacity could reach 70 GW. If the growth continues at the same pace large areas of the North Sea will be used for offshore wind up to an average of 10% or even 20% for instance in the Dutch Exclusive Economic Zone in 2050. This means that it is not to be taken for granted that enough space is available.

In the Mediterranean similar issues may arise but with different focus e.g. related to floating wind farms.

Social responsible design, co-creation and integrated ecosystem development can be divided into the following aspects:

- Sincere stakeholder discussion (participation in planning) and wind farm design taking into account their interests, finding an optimal design that is not only aiming at the lowest LCoE for offshore wind, reduces (also in the longer run) resistance and increases the societal value.
- Securing local content, thus strengthening the local economy, enhances public support for offshore wind.
- Investigating opportunities for (financial) participation: municipalities and people can realize parts of their CO2 reduction targets, pension funds can be involved making a connection to a CO2 neutral future and future and climate proof low risk investments
- Impact on coastal communities
- Multipurpose use for economic purposes: fishery can harvest crabs etc.; shipping lanes should be included in design of large wind farm area's; seaweed farming in wind farms
- Enhancement of nature by designing scour protection (and leaving it after removal of the foundation); creating nursery area's for fish species;
- Taking into account environmental aspects, ecological research and life cycle optimization
- Health and safety should have high priority when working offshore; R&D should focus on reducing offshore activities
- Design of low noise installation methods for foundations; research into low impact wind
- Making energy supply more reliable and environmentally friendly (for this we refer to the topic system integration)

State of the art: Integrated social responsible design and co-creation are relative new concepts, although elements like stakeholder involvement are long known. This has resulted in a number of activities both on international and at national level (see below)

Non-technological aspects: Barriers for large scale offshore wind implementation can result from cost, technological or societal issues. For a technology push industry it may be difficult to overcome especially the more soft barriers.

Spatial planning is a crucial element for the future development of offshore wind and it is therefore important that Maritime Spatial Plans under development in Member Countries according to the Directive 2014/89/EU take properly into consideration the potential for offshore wind farming, including synergies with other sectors (i.e. aquaculture, wave energy, O&G, tourism).



Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/Party	Budget
North Sea Energy Lab: ZEEE	<p>The NSE Lab (ZEEE) explores possible approaches to develop a sincere involvement of other users of the sea. Especially fishery and nature potentially are opponents to the large development of offshore wind. The three E's in ZEEE stand for Protein's, Ecology and Energy (in Dutch all words start with an "E").</p> <p>Innovative ways of cooperation: such as "co-creation", learning journeys and more usual ways like workshops, are used to create mutual understanding and trust between the parties. The goal is to come up with solutions that prevent major hurdles for the roll out of offshore wind, and to create mutual benefits where possible. Also, parties that face unpreventable economic losses should be compensated.</p> <p>Research into the following issues can be considered: Combined use of space: fishery in wind farms that does not interact with the soil; nature enhancement, tourism, sea weed farming all may add (societal) value. Especially when wind farms are developed near shore, the interests of coastal regions should be considered. Further, minimizing negative impacts, mitigating unavoidable impact or creating added value all can be considered.</p> <p>Pilots with these options are a good opportunity to gather experience in an early stage.</p> <p>(see http://www.mvi-labs.nl/northseaenergy)</p>	2017 - 2019	This Innovation Programme is started under the Topsector Energy. It is a collaboration between TKI Wind op Zee, NWEA, Nogepe, and various private experts. It may be further developed into a multi annual innovation programme to facilitate the energy transition	TBD
Name H2020-MUSES	<p>Description:</p> <p>The Multi-Use in European Seas (MUSES) project will look at how European seas are currently being used and what could be the real multi-uses opportunities. The Multi-Use in European Seas (MUSES) project will review existing processes, used across the EU, for marine and coastal development to ensure they are sufficient for the sustainable, multi-use of the marine environment. The project will provide Regional overviews of the EU sea basins, including: Baltic Sea, North Sea, Mediterranean Sea, Black Sea and Eastern Atlantic. A comprehensive set of case-studies will also be conducted and analysed and an action plan will be put forward to look at how to: build on and reduce gaps in existing knowledge, identify impacts and risks and maximise local benefits while overcoming existing barriers.</p>	Timeline Nov 2016 – Oct 2017	Location/Party EU Sea Basins, including the Mediterranean	Budget 2 ME
Name EASME/EMFF-SUPREME	<p>Description:</p> <p>SUPREME (Supporting maritime spatial Planning in the Eastern Mediterranean) will focus on two key objectives: 1. To supporting the implementation of Maritime Spatial Planning in EU Member States; 2. To launch and carry out concrete and cross-border MSP initiative between Member States.</p>	Timeline Jan 2017 – Dec 2018	Location/Party Eastern and Central Mediterranean	Budget 2 ME



Name GROW Growth Through Research, development and Demonstration in Offshore Wind	Description: "Growth through Research, development & demonstration in Offshore Wind" – a consortium of around 20 leading players to reduce the costs of offshore wind to a competitive level in the near future. In the next 5 years, research institutes and companies active across the entire offshore wind value chain will cooperate in GROW and bring innovations to the market. GROW identifies 11 program lines. One of these is the integration of offshore wind in the North Sea. (see www.grow-offshorewind.nl)	Timeline: 2017 - 2022	Location/Party: This Innovation Program is a cooperation between 15 industrial Partners and the 5 main Dutch knowledge institutes.	Budget In total the budget of GROW amounts to 100M€. For PL 11 the budget has still to be fixed
Name 6th Energy Research Programme of the Federal Government (DE)	Description German R&D activities for energy efficiency and renewable energies including Offshore Wind Energy. The emphasis is on innovative energy technologies that meet the requirements of the energy transition. The research priorities are stressing amongst others technological development of Offshore Wind Energy by specific cost reduction, increase of power output and availability as well as enhancing environmental compatibility. Especially environmental aspects and ecological research with the focus on standardization and technical innovation for Offshore Wind Energy (by noise reduction, mitigation measures), and also lifetime optimization are subject of this R&D programme. Also comprehensive aspects of health & safety and social acceptance of Offshore Wind Farms play an important role. See: http://www.bmwi.de/Redaktion/EN/Artikel/Energy/research-for-an-ecological-reliable-and-affordable-power-supply.html	Timeline: 2011-2018 (to be followed by 7 th Energy Research Programme)	Location/Party: This German national research programme is open for universities, research institutes and enterprises	Budget: 340.7 m € from 2012 to 2016 for new on- and offshore wind energy projects
Name EoIMED,	Description The EoIMED project is a French pilot floating wind farm of 24 MW (4 wind turbines) in the Gruissan zone (Mediterranean, France), under creation by the consortium piloted by the Quadran Group (https://www.quadran.fr/index.php/en/wind-power/offshore).	Timeline:	Location/Party:	Budget



Name INTACT	Description The INTACT project is a joint industry and government project. The primary objective for this R&D project is to develop measures and procedures to reduce the risk of bird – wind turbine collisions. The main focus of the research will be to test promising deterrent measures (contrast painting rotor blades, contrast painting tower bases, UV lighting, operational mitigation) and develop tools to facilitate this, and to test and refine GIS-based micro-siting tools. The perceived tools and measures, to be developed and tested at the onshore Smøla wind-power plant, are envisioned to enable transference for development of environmental-friendly wind energy offshore. For more information on the project please go to : http://www.nina.no/english/Research/Projects/INTACT	Timeline:	Location/Party:	Budget
Name INTACT	Description The INTACT project is a joint industry and government project. The primary objective for this R&D project is to develop measures and procedures to reduce the risk of bird – wind turbine collisions. The main focus of the research will be to test promising deterrent measures (contrast painting rotor blades, contrast painting tower bases, UV lighting, operational mitigation) and develop tools to facilitate this, and to test and refine GIS-based micro-siting tools. The perceived tools and measures, to be developed and tested at the onshore Smøla wind-power plant, are envisioned to enable transference for development of environmental-friendly wind energy offshore. For more information on the project please go to : http://www.nina.no/english/Research/Projects/INTACT	Timeline:	Location/Party:	Budget
IEA	IEA Wind TCP Task 28 “Social Acceptance of Wind Energy” and Task 34 “WREN – Working Together to Resolve Environmental Effects of Wind Energy ” to which also European countries are contributing			

International cooperation:

Name MERMAID, TROPOS, H2OCEAN	Description: Three projects have recently been concluded under FP7 (MERMAID, TROPOS, H2OCEAN), elaborating and developing the concept of Multi-Use Platform (MUP), including energy related uses and economical / social / environmental feasibility and acceptance.	Timeline: start and end dates	Countries involved	Budget per country
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Title: 8.1 a Water treatment in offshore windfarms for Crab and lobster cultivation

Targets: Demonstrate the feasibility of crab and lobster cultivation in windfarms

Description deliverable: In wind farms regular fishing activities that disturb the soil are in general speaking not possible because of possible damage to cables. Fishery in the North Sea is under pressure as more and more areas may become inaccessible for regular ships. A combination of crab and lobster cultivation may provide a solution for a selection of the fishery companies. Interference with the operation of the wind farm should be avoided. Possibly the fishers can help with monitoring (ecological) or transport of personal can be combined. Pilots are needed to investigate the consequences

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 3 million - see Table 1 core text

Title: 8.1 b Research on impact of Sea weed farming on wind energy farms

Targets: Demonstration of possibility of the combination of sea weed farming and wind

Description deliverable: Pilot demonstrating the production of seaweed in wind farms. By combining wind farms and sea weed farming.

Offshore projects require substantial budgets. A pilot project for multipurpose use of the wind farm can have a limited return on investment, since there are benefits from produced energy and sea weed. Projects like this need to be defined in detail and feasibility studies are required to establish the required investments and the potential benefits. In some cases even legal aspects have to be settled and permits are requested to be able to implement the pilots. Consortia need to be established for the realization of this kind of pilot projects. Only then it will become clear what the share of governmental subsidies or what actions are required from the government (legal aspects, permits) are required to be able to realize the projects by commercial organizations.

TRL: 6 – 9 Industrial research & demonstration

Total budget required: EUR 3 million - see Table 1 core text

Title: 8.1 c Artificial reefs for oysters

Targets:

Creating artificial reefs may help to again let oyster banks develop and thereby restore the natural environment of the North Sea.

Description

Oyster banks, or the “corals of the North Sea” show a high biodiversity and can therefore help to restore the natural environment in the North Sea. Combination with areas where wind farms are build and thus limited other activities are allowed may create good opportunities for mutual benefits between nature and energy production. The first step in these developments should be pilots at a limited scale. It is uncertain if the scour protection is suitable for the creation of the reefs

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 3 million - see Table 1 core text



Title: 8.2 Concept development floating wind farms, acceptability and multifunctional uses

Targets:

- Identification of potentials at basin scale, based on a multi-criteria analysis
- Identification of real and perceived barriers (technological, legal, social, economic, environmental) and of actions to overcome them
- Identification of synergies (share of space, infrastructures, skills, information, etc.) with other uses and ways to promote them
- Improve sharing of data and information of interest, from the feasibility and design phase to the operational phase (i.e. build a dedicated geoportal with own information and interoperation access to data of interest from existing geodatabases)
- Develop common methodologies and tools to support analysis and decisions
- Involvement of non-EU countries to promote the exploitation of their potential and their socio-economic growth
- Feeding and influencing Maritime Spatial Plans under development at EU country level

Description**deliverable:**

A large-scale analysis on potentials for floating wind farms, their acceptability and related multifunctional uses is needed to set the baseline for future more specific actions on a multidimensional / multiactor / multigovernance level. This is needed for the Mediterranean, the Atlantic ocean as well as other deep seas in Europe. The analysis will propose as a whole an Action Plan to remove bottlenecks to future expansion of the floating wind sector.

The multi-criteria analysis to be carried out at basin scale to identify potentials and barriers will consider and integrate several aspects such as:

- wind climate, seafloor morphology and structure
- grid connectivity and energy management solutions
- ports and infrastructures
- local skills, industries, clusters
- ecosystems and protected areas
- conflicts and synergies with coastal and sea uses
- legal and administrative framework

Among the specific targets to be reached, listed above, several of them represent themselves or are in very close connection with concrete results, i.e. pilot / demonstrators or actual installations.

The activity is key and timely also because it will properly influence the preparation of the Maritime Spatial Plans, to be finalised by Member Countries by year 2021, indicating the most suitable areas for offshore wind development, the expected benefits and suggesting planning measures (spatially and non spatially based).

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 5 million - see Table 1 core text



Title: 8.3 Feasibility study on offshore research infrastructure development: social, environmental, coexistence and multi-use, legal aspects.

Targets:

- Identification of potentials at national scale, based on a multi-criteria analysis
 - Identification of real and perceived barriers (technological, legal, social, economic, environmental) and of actions to overcome them
 - Identification of synergies (share of space, infrastructures, skills, information, etc.) with other uses and ways to promote them
 - Improve sharing of data and information of interest, from the feasibility and design phase to the operational phase (i.e. build a dedicated geoportal with own information and interoperation access to data of interest from existing geodatabases)
 - Develop common methodologies and tools to support analysis and decisions
 - Promote a better coordination among central and regional / local administration on the subject, from policy development to implementation of specific projects
 - Promote a better coordination among the national marine/maritime community / stakeholders having interests on the subject
 - Promote the subject, together with other Blue Growth topics, for a wider and consistent inclusion within the regional Smart Specialisation Strategies
-

Description

deliverable:

The proposed R&I activity

- Modelling in large detail and at in high resolution the offshore situation
 - Promote the consolidation of the innovative Technological Cluster on Blue Growth
 - It will trigger concrete actions at regional level, through Structural Funds managed according to the identified Smart Specialisation Strategies
 - It will favour the development and establishment of a pilot/demonstration site and contextualize it within the national frameworks
 - contribute to the identification of the demonstration sites, as far as environmental, legal / administrative, social acceptance aspects and coexistence with other uses are concerned.
 - The same aspects will be covered during the design and permitting phase.
 - Engagement of local / regional stakeholders will be promoted in order to assure best acceptance of the pilot.
 - Environmental monitoring will be carried out during installation and exercise, at local and wide area scale and also in connection with other possible uses of the site
-

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 5 million - See Table 1 core text

Title: 8.4 EU coordinated monitoring of impacts of wind farms during installation and operation

Targets: Monitoring, understanding and reporting of impact of wind farms to their environment

Description

deliverable:

Monitoring, understanding and reporting of impact of wind farms to their environment.

TRL: 6 – 9: Industrial research & demonstration

Total budget required: EUR 15 million - see Table 1 core text



Annex: Priority Action 9: Human Capital Agenda

Declaration of Intent

Summary:

The realization, operation and maintenance of wind farms entails many disciplines and asks for much knowledge, expertise and skills. The need for skilled professionals in the offshore wind sector is rapidly growing. Not only is the deployment of new wind farms accelerating, the installed based is growing, resulting in a growing need for operation and maintenance personnel. At present there are estimates available for the total number of jobs in the near future by Irena and by WindEurope. These estimates give only global overviews about the employment, without specifying the need for specific functions. When analyzing the life cycle of wind farms from development until decommissioning it becomes clear that many different job roles can be distinguished. GreenPortHull has inventorised more than 120 job roles, within all educational levels, each with their specific competences. Given the already existing shortages in the labor force, we can not allow any obstacles in the labour market by limiting the transfer of personnel between countries and sectors. This is why education should be harmonized within the EU.

Targets

- Post graduate training courses (or PhD positions) for wind offshore engineers
- Specialized courses on system integration, in terms of the energy supply (grid configuration, storage and Power2X) and cooperation/synergy with other sectors or human marine activities (fishing farm, aquaculture, methanol production, hydrogen production)
- Master business administration courses for new functions in the offshore wind sector
- Post graduate training courses for offshore wind turbine maintenance and decommissioning
- Standardized competences for vocational trainings



State of the art:

Academic level

In most of the European countries, the education of professionals with in-depth scientific and technological knowledge on offshore wind turbine is well established, in particular for bottom fixed structures.

However, the growing demand for floating OW turbines (FOWT) and structures asks for a widening of the basic knowledges of the young engineers towards the design of FOWT, to meet the European Industrial requests for new professional figures. The rapid and growing steps forward of the fundamental and applied research for more efficient and even more accurate methodologies claim for post-graduate courses to fill the gap between the industrial requirements and the available professional skills.

Furthermore, the need to reduce the LCoE for Offshore Wind resources requires new professionals able to integrate the FOWT within a business plan system which is attractive for new private and public funding. Installation, maintenance and use of marine renewable energies require new expertise on the management of the energy plant, from the first stage, in terms of national permissions and regulations to the standard use, in terms of optimal and profitable practice.

To the purpose, FOWT could be integrated with existing marine activities, e.g. aquaculture, as well as with other renewable marine resources, e.g. wave energy converter, within the overall framework of a sustainable use of the marine resources. Finally, marine operations for FOWT installation and maintenance are an issue that must be faced within specialized training courses for technicians working in the sector.

Existing programs and activities

Most of the European countries activated specific Bachelor or Master of Science courses on Offshore Wind Turbine. Specific information can be found in the web site of the main Universities in Europe.

Master courses supported by EU commission exist; among them:

- In North Europe, DTU, NTNU, TUDelft, UniOi, founded the European Wind Energy Master (EWEM), an Erasmus Mundus Master Course supported by the European Commission. This is a M.Sc. program with a duration of 2 year, focusing on wind energy system and offering 4 different specializations: Electrical Power Systems, Offshore Engineering, Rotor Design and Wind Physics.
- Master's program in Renewable Energy (RENE): offered by five European universities through InnoEnergy. After successfully completing the program and the thesis, the student will receive a master's degree from two of the institutes in the form of a double diploma. Companies like Total, EdF, Energias de Portugal (EDP), and Iberdrola are actively involved in the program.
- The association of European Renewable Energy Research Centres (EUREC) proposed and coordinates two different Master Programs:
 - European Master in Renewable Energy (EMRE), whose aim is to train post-graduate students to fill the gap between the growing industry demand for specialized renewable energy expertise and the skills currently available on the job market.
 - European Master in Sustainable Energy System Management (SESyM) which focuses on the multidisciplinary aspects of energy systems. It provides management and communication skills, as well as the technical, legal and economic frameworks of the system integration of all energy resources.

Vocational level

At vocational level the focus should be on O&M technical skills. Multi-disciplinary skills are critical to the development of the O&M sector, currently accounting for some 20% of wind industry employment. The quality of vocational training should be improved. Because of the international character of the industry it makes sense to harmonise curricula and qualifications. Incorporating industry experience into training and education would benefit current and future students. Industry and education could jointly fund internships.

Non-technological aspects: To increase the inflow of personnel the image of offshore wind needs to be improved or highlighted and marked as the driver for Europe energy future. This requires activities on all levels of education (even from primary level) but also on PR regarding the challenges and opportunities the industry faces.



Ongoing R&I Activities (Flagship activities or not): relevant to achieving the targets

Name	Description:	Timeline:	Location/Party	Budget
VET network	<p>sustainable network on O&M in (offshore) Wind with VET (Vocational Educational Training) and companies</p> <p>Activities:</p> <ul style="list-style-type: none"> - Description of the state of the art of each educational partner <ul style="list-style-type: none"> • Programme (content, level, length) • Certification/standards • Workshop • Internship • Competencies of teachers • Number of students, • Cooperation with industry • Funding/finance - Exchange of teachers and trainers - Description of the desired situation in each country and international - Preparation of stage 2: a further project in ERASMUS+ or in Interreg B/C 	2018-2019	Enterprises and institutions from Germany, Denmark, Ireland, Norway, Netherlands	

Title: *9.1 Marie Curie ITN Projects focusing on the education of PhD candidates working on FOWT*

Targets: *Education of PhD candidates working on FOWT*

Description deliverable: Specific support mechanisms to train PhD students in close collaboration with universities, research institutes and industry on specific wind energy topics.

TRL: NA

Total budget required: EUR 5 million - see Table 1 core text



Title: 9.2 European Centre of Excellence for OWT

Targets:

Foundation of a European Centre of Excellence for OWT, with possible synergies with the other marine energy resources, in the spirit of the system integration within the energy island concept. The excellence level of the ECoE will pave the way to offshore wind farm system optimization design and train teams with multidisciplinary and different levels of expertizes, from technical to innovation ability, which are engaged in designing and running wind farm to manage wind-power electricity generation and wind farm design.

Description deliverable: The ECoE-OWT, fully funded by the EU countries, should become an international recognized educational centre where PhD students or engineers could find the best solution to improve their expertise in the sector, working within specialized and interdisciplinary teams, led by worldwide recognized teachers. They will have the opportunity to follow a novel programme resulting from the combination of the expertise from public research, academic and non-academic partners managing the training programme on soft skills and the coaching programme on Technological Innovation and Entrepreneurship. A very distinctive aspect of the ECoE will be the training on Technological Innovation and Entrepreneurship aimed at stimulating the scientific and technological skills (from the aero-hydro-structural design, to the integration in the electrical system, maintenance and decommissioning) but also the entrepreneurial attitude of the students. The centre should be located in a single area but with satellite sites to perform experiments on model tests (e.g. CNR-INSEAN, PoliMi, Univ. Lecce in Italy), also through natural lab existing in Europe (e.g. NOEL in Italy) and/or on full scale prototypes. The experimental test areas will be identified based on the different geographical location and different meteo conditions. The centre should collect experimental and numerical data within a database that can be used by the partners of the centre, becoming attractive also for private funding from Industries and SME.

TRL: NA

Total budget required: EUR 15 million - see Table 1 core text

Title: 9.3 Wind Energy Hubs

Targets:

Harmonisation of curricula and training techniques in close cooperation between Vocational Education and Training centres and industry, including dissemination of appropriate educational content and techniques. Development of international internships/apprenticeships for students.

Description

Development of a closer relationship between industry, VET, higher education and R&D - through the establishments of both physical Wind Energy Hubs where industry are partly collocated and/or in closer cooperation with commercial training centres and public VET - and even EQ level 5 or even higher, to incorporate synergies throughout industry - Technical VET - Higher Tertiary Education and industry. Explore the transition of competence and experience from the offshore oil and gas H&S operations and training, towards the needs of a more secure and well developed operation and training of H&S towards offshore wind? Health and safety and its standards (EU/ Worldwide); Equipment; Investigation of the possibilities to harmonize H&S training in offshore oil and gas, maritime and (offshore) wind.

TRL: NA

Total budget required: EUR 5 million - see Table 1 core text



ANNEX 2 Temporary Working Group on Offshore Wind

Following the endorsement of the Declaration of Intent by the SET-Plan Steering Committee on 20 January of 2016, the Temporary Working Group for Wind Energy was set up. The group was set up following the common principles of the SET-Plan steering committee guiding the preparation of the Implementation Plans. The members of the working group are coming from 12 different SET-plan countries forming a balanced group of stakeholders, representing government (agencies), industry, research associations and education and the European Commission. The nomination of the Chair and Co-chair took place before the first WG meeting on invitation of the EC:

- Chair of the TWG OW: Ernst van Zuijlen (TKI Offshore Wind) representing the Netherlands
- Co-Chair of the TWG OW: Aidin Cronin (ETIP wind)

Members of the Temporary Working Group on offshore wind energy:

NL	Ernst van Zuijlen (Chair, Topsector TKI wind)
NL	Martine Roza
NL	Bram van der Wees
NL	John Baken
BE	Reinhilde Bouckaert
BE (Walloon region)	Pascal Lehance
BE (Flanders)	Lut Bollen
DE	Franciska Klein (Project Management Jülich PtJ, Forschungszentrum Jülich GmbH)
DE	Martin Weber (Project Management Jülich PtJ, Forschungszentrum Jülich GmbH)
ES	Inmaculada Figueroa
ES	Ignacio Cruz (CIEMAT)
FR	Sylvain TRAVERSA
FR	Nicolas TONNET (ADEME)
IT	Mr. Claudio Lugni (CNR)
DK	Hanne Thomessen (EUDP)
EE	Siim Meeliste
NO	Harald RIKHEIM, RCN
TR	İlknur YILMAZ, Cagri YILDIRIM
UK	Steve Martin (BEIS)
DK	Aidan Cronin (Chair ETIP Wind)
DK	Peter Hauge Madsen (Chair EERA JP Wind)
NO	John Olav Tande (EERA JP wind)
IE	Jimmy Murphy (UCC)
EC - RTD	Matthijs Soede
EC - ENER	Mark van Stiphout
EC - JRC	Andreas Uihlein
EC - ENER	Roberto Gambi
EC - JRC	Thomas Telsnig
EC - RTD	Dermot Buttle



The TWG on offshore wind convened for the first time on 16 December 2016 to discuss, develop and agree the process the members would follow in creating this Implementation Plan. The group discussed intensively the targets of the Declaration of Intent due to the development in the Offshore Wind market.

After the first meeting the group met on 22/3/2017, 26/9/2017, 29/11/2017, 23/1/2018 and 26/4/2018. The Working Group identified what activities and supports were in place in the participating countries and how these would contribute to the realisation of the targets as defined in the Declaration of Intent.

In the definition of the priority actions the Strategic Research and Innovation Agenda (SRIA) from the European Technology and Innovation Platform on Wind Energy¹² (ETIP Wind) and the subprogrammes of the European Energy Research Alliance¹³ Joint Programme (EERA JP) on Wind Energy were considered. Priority actions considered in this Implementation Plan needed the involvement and support of at least two SET-plan countries.

¹² Strategic research and innovation agenda SRIA 2016; ETIPWind

¹³ EERA Joint Research Programme 2017



ANNEX 3 Financing/Funding sources

National funding controlled by Member States

Most Countries have Research and Innovation programmes, usually limited to Technology Readiness Level (TRL) 7. Some countries have specific programmes for wind energy development, but in general the countries have general funding schemes. An example of a specific programme focussed on offshore wind is the Dutch TKI Wind op Zee. This programme is covering all areas in offshore wind and has a total budget of EUR 70 million. The programme is open for research institutes, universities and enterprises and is open for international cooperation.

Higher TRL financial support provided by Member States need to comply with the EU's State aid rules. Relevant documents are two Commission Communications: 1. Framework for State aid for research and development and innovation¹⁴, which limits aid intensity for applied research undertaken by large enterprises to 60% (or 70% in case of cross-border cooperation or cooperation with an SME or a research organisation); 2. Guidelines on State aid for environmental protection and energy 2014-2020¹⁵ which in the case of CCS, energy infrastructure, district heating infrastructure and aid in the form of tradable permits allows for a higher aid intensity (up to 100%).

Important Projects of Common European Interest (IPCEI) are transnational projects of strategic significance for the EU. In 2014 the European Commission adopted specific State aid guidelines for IPCEIs¹⁶ allowing Member States to provide financial support to such projects undertaken by industry beyond what is usually possible for R&D and innovation projects. For example, public funding may also support the first industrial deployment of the results of an R&D project and may cover a higher percentage of the funding gap. An example is the IPCEI on High Performance Computing (HPC) and Big Data Enabled Applications launched in January 2016 by Luxembourg, France, Italy and Spain¹⁷.

Within European Structural and Investment Funds (ESIF), the relevant fund is the European Regional Development Fund (ERDF). However, the ERDF Regulation stipulates prohibits supporting investments to achieve greenhouse gas reductions from activities covered by the ETS. R&I activities can nevertheless be supported if they are included in the Smart Specialisation Strategy of the respective Member States or region¹⁸. This is a bottom-up process, hence the initiative would need to come from the Member State.

EU funding

Currently available EU grants are limited to Horizon 2020 (2014-2020) and the Research Fund for Coal and Steel (RFCS¹⁹), which, however, are not aimed at TRL higher than level 7. From 2021 it is

¹⁴ [http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52014XC0627\(01\)](http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52014XC0627(01))

¹⁵ <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014XC0628%2801%29>

¹⁶ http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.C_.2014.188.01.0004.01.ENG

¹⁷ https://ec.europa.eu/commission/commissioners/2014-2019/oettinger/blog/luxembourg-launches-supercomputing-project_en

¹⁸ <http://s3platform.jrc.ec.europa.eu/>

¹⁹ Could be interesting for R&I projects in the steel industry requiring co-funding of not more than around EUR 3 million (http://ec.europa.eu/research/industrial_technologies/rfcs_en.html)



expected that the new Horizon Europe programme will be in place to support EU Research and Innovation projects

The Innovation Fund (IF) is proposed by the Commission as part of a reformed Emission Trading System (ETS). The type of instrument (grant, loan, guarantee) is not yet decided, it might depend and evolve with the maturity of the project. Current planning is to adopt a Delegated Regulation setting the Fund's detailed rules in the first half of 2018 with the Fund being operational in 2020. Before 2021 (and conditional to the new ETS Directive being adopted) available funding are the proceeds from 50 million ETS allowances from the Market Stability Reserve and the leftovers from NER300 (up to EUR 1 billion). For the period from 2021 to 2030, proceeds from an additional 400 million (Commission proposal) or 600 million (European Parliament amendment) ETS allowances would be available. The value of one allowance is the price of ton of CO₂, when the allowance is auctioned (today the ton of CO₂ is valued at around 5 EUR, but it is expected to be higher with the implementation of the proposed ETS reform).

The Commission proposal for a new ETS Directive defines the scope of the Innovation Fund rather broadly: demonstration projects in the areas CCS, innovative renewable energy technologies and low-carbon technologies and processes in industrial sectors covered by the ETS. The Innovation Fund could cover a maximum of 60% of the costs of projects.

The European Fund for Strategic Investment²⁰ (EFSI) ("Juncker Plan") can be relevant in case projects expect to have a business case / achieve a Return on Investment (possible with complementary funding by grants) and the main hurdle is the reluctance of banks to provide loans to inherently risky innovation projects. A key objective of EFSI is to leverage additional private funding, hence EFSI may be most appropriate for R&I activities rather close to the market and with confirmed revenue support

InnovFin-EDP²¹ (Energy Demo Projects) enables the EIB to finance innovative first-of-a-kind demonstration projects in the fields of renewable energy, sustainable hydrogen and fuel cells. In projects focusing on hydrogen production/distribution, the hydrogen should come primarily from renewable sources. The projects may include first-of-a-kind power, heat and/or fuel production plants and first-of-a-kind manufacturing plants. The EIB provides loans of between EUR 7.5m and EUR 75m. InnovFin-EDP has been designed to address the financing bottleneck identified in the EU's Strategic Energy Technology (SET) Plan. EIB loans are subject to a project's bankability prospects, meaning that they will only be for projects very close to the market and with confirmed revenue support.

²⁰ <http://www.eib.org/efsi/>; https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan_en

²¹ http://www.eib.org/attachments/thematic/innovfin_energy_demo_projects_en.pdf