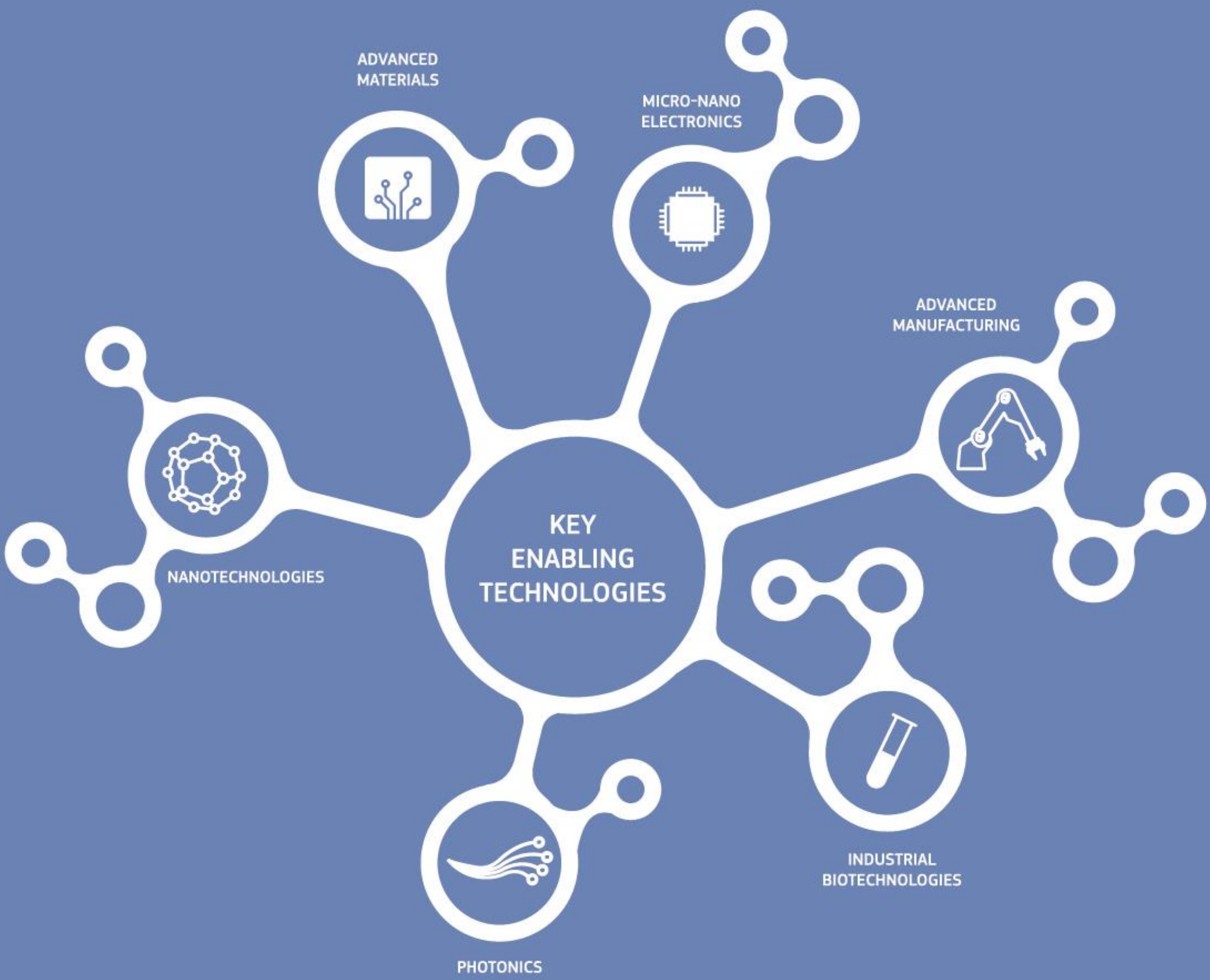
European Commission

KETs OBSERVATORY PHASE II



SENSING AND MONITORING SYSTEMS FOR OFFSHORE WIND TURBINES

Report on promising KETs-based products nr. 8

Contract nr EASME/COSME/2015/026

Internal Market, Industry, Entrepreneurship and SMEs

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European Union, August 2017.

KEY ENABLING TECHNOLOGIES OBSERVATORY

Executive summary

The current report aims to provide stakeholders with an analytical base, helping to strengthen cross-regional cooperation mechanisms to boost the deployment of Key Enabling Technologies in Europe. The report specifically aims to highlight the value chain, key players and constraints at the European level for the domain of sensing and monitoring systems for offshore wind turbines. It also addresses the key strengths and potential of the EU regions, as well as promising business opportunities and key risks and challenges. Finally, the report elaborates on specific policy recommendations with both immediate focus and long-term orientation.

Sensing and monitoring systems for offshore wind turbines focus on obtaining reliable information on the state and condition of different critical parts, in order to detect and/or predict damage before it reaches a critical stage. The use of these technologies allows companies to schedule actions at the right time, and thus helps reduce the costs of operation and maintenance, resulting in an increase of wind energy at a competitive price and thus strengthening productivity of the offshore wind energy sector. In the domain of sensing and monitoring for offshore wind turbines, Europe is reported to be the strongest player in research, production and manufacturing.

The value chain for sensing and monitoring systems for offshore wind turbines is very dynamic and comprises multiple actors spread across Europe. Although, all the activities of the value chain are covered by European actors, different constraints need to be tackled in order to unlock its full potential. Overall, some ground-breaking systems are encountering difficulties to pass prototype stage. In addition, some newcomers and small players are facing challenges to interact with consolidated players and demonstrate the effectiveness of their technologies. Finally, another challenge that should be considered is the high cost of novel and effective sensing and monitoring systems.

Europe is a global leader in the offshore wind energy market and has all the necessary assets and key players to maintain this dominant position in the sensing and monitoring systems sector. Offshore wind energy market is expected to grow exponentially in the upcoming years, attracting interest from new markets. Stakeholders suggest that in order to avoid losing Europe's competitive advantage to China, Japan or the United States, public support to keep the innovation trend should be maintained. As actors are spread across diverse EU regions, cross-regional cooperation is key to help unleash Europe's full potential.

Several measures could be envisaged in order to support the adoption of innovative sensing and monitoring systems for offshore wind turbines. In particular, there is a need to promote demonstration and testing in real condition environments; foster open collaboration among industry actors; and develop EU guidelines regarding operation and maintenance activities. Long-term measures should focus on ensuring a stable support to wind energy; training multidisciplinary professionals; and ensuring financial incentives to improve the uptake of new sensing and monitoring systems for offshore wind turbines.

1. Introduction

The current report has been developed in the context of the second phase of the KETs Observatory initiative. The KETs Observatory represents an online monitoring tool that aims to provide quantitative and qualitative information on the deployment of Key Enabling Technologies[1] (hereafter "KETs") both within the EU-28 and in comparison, with other world regions. Specifically, the KETs Observatory represents a practical tool for the elaboration and implementation of Smart Specialisation Strategies in the EU regions.

1.1 Background

A key challenge for the EU competitiveness policy is to enable European industry to move to the higher end of the value chain and position itself on a competitive path that rests on more innovative and complex products. For many KETs, this implies a focus on more integrated technologies with the potential of connecting several KETs.

To this end, one of the key tasks of the KETs Observatory implies identifying and describing "promising KETs-based products" and their value chains, and recommending specific policy actions to help the EU industry stay ahead of global competition. Promising KETs-based products here can be defined as emerging or fast-growing KETs-based products with a strong potential to enhance manufacturing capacities in Europe. Such products correspond to KETs areas where Europe has the potential to maintain or establish global industrial leadership leading to significant impacts in terms of growth and jobs.

1.2 Objectives of this report

In the context of the second phase of the KETs Observatory, in total, 12 promising KETs-based products have been selected for an in-depth analysis of their value chain, the associated EU competitive position and the corresponding policy implications. The selection of the topics stems from a bottom-up approach based on active engagement of regional, national and EU stakeholders through the S3 Platform for Industrial Modernisation[2].

This report presents the results of the abovementioned in-depth analysis for one of the selected top-priority topics, namely **sensing and monitoring systems for offshore wind turbines**. The analysis is based on desk-research and in-depth interviews with key stakeholders. The report aims to provide relevant stakeholders with an analytical base helping to establish or strengthen cross-regional cooperation mechanisms to boost the deployment of KETs in Europe.

1.3 Target audience

The report aims to provide key market insights for sensing and monitoring systems for offshore wind turbines and identify key directions for action in order to maintain Europe's

[1] Namely Nanotechnology, Micro-/Nanoelectronics, Industrial Biotechnology, Advanced Materials and Advanced Manufacturing Technologies
[2] http://s3platform.jrc.ec.europa.eu/industrial-modernisation

competitive position on the global market. The report specifically targets the EU, national and regional policy makers and business stakeholders who are currently involved in or consider engaging in cross-regional cooperation mechanisms. The report may also be relevant for other key stakeholder groups including academia, as well as different support structures such as cluster organisations, industry associations and funding providers.

2. Key product facts

In the current section, we provide a brief introduction to sensing and monitoring systems for offshore wind turbines. We also elaborate on the market potential and the importance of this product for the EU competitiveness.

2.1 Introduction to the product

Sensing and monitoring systems for offshore wind turbines are technologies that build on the potential of lowering offshore wind power operational and maintenance (O&M) costs. These technologies focus on obtaining up-to-date reliable information on the state and condition of the different critical parts of offshore wind turbines. The gathered data is then analysed using dedicated algorithms in order to extract the important features that will help to detect and predict damage before it reaches a critical stage[3].

The process of sensing and monitoring systems involves the use of:

- an integrated sensing network, consisting of the sensor itself, communication infrastructures, software control and processing algorithms;
- data interrogation, including signal processing and feature extraction;
- and statistical assessment, incorporating the classification of damage existence, its location, and/or the type[4].

Sensing and monitoring systems for offshore wind turbines build upon the technologies used in onshore farms. However, the challenging conditions under which they operate call for additional functionalities. Offshore wind turbines are exposed to harsh environmental conditions such as changing air pressure and temperature; dustiness; humidity; and unpredictable loads[5]. In addition, being hard-to-access structures, replacing and repairing failed components usually require service crews, cranes and lifting equipment. The latter, further to downtime loss of power generation, impacts on the cost of wind energy.

Operation and maintenance (O&M) costs can account for up to 30% of the levelised cost of energy (LCOE) for an offshore wind farm[6]. Development of turbine size, water depth and distance from shore will increase O&M prices. Indeed, with an additional capacity of 1.558 MW[7] in 2016, 338 new offshore wind turbines installed[8], and a target share of the EU wind energy by 20% by 2020[9] and 27% by 2030[10], the identification of structural risks and mitigation actions becomes a high priority for supplying electricity at cost effective

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[3] Obrski P. (2014), "Developments in integration of advanced monitoring systems", International Journal Advance Manufacturing Technology – August 2014

[4] Mukhopadhyay S. (2011) "New Developments in Sensing Technology for Structural Health Monitoring" Lecture Notes in Electrical Engineering nº96, Springer

[5] Nye M., Wang L., (2013) "Review of condition monitoring and fault diagnosis technologies for wind turbine gearbox" 2nd International Through-life Engineering Services Conference, available at: Science Direct.

[6] May, A., McMillan, D., & Thöns S. (2014). Economic analysis of condition monitoring systems for offshore wind turbine sub-systems. In Proceedings of EWEA 2014

[7] Power Plant

[8] European Offshore Wind Industry Key Trends Statistics 2016, Data retrieved from https://windeurope.org/about-wind/statistics/offshore/european-offshore-wind-industry-key-trends-and-statistics-2016/

[9] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance)

[10] EU 2030 Framework for climate and energy, available at: https://ec.europa.eu/energy/node/163

levels. Sensing and monitoring systems could help attain the expected fall to 100 EUR/MWh by 2020[11]of offshore wind energy cost. Reliable and low operational costs will ensure offshore wind energy costs approach non-renewable levels[12].

Research and commercialising technologies in areas of O&M are shifting from unscheduled corrective maintenance towards scheduled preventive maintenance. The use of different types of sensors and signal processing equipment applied to the main parts of wind turbines such as blades, gearboxes, generators, bearing and towers is set to anticipate defaults before they occur[13]. Indeed, predictive field maintenance will detect alteration in wind turbines long before they can jeopardise the integrity of the structures. This will allow companies to schedule actions at the right time, minimising the impact of unplanned downtime[14]. Therefore, early detection will help reduce maintenance expenditures, since the necessary repairs will be both simpler and less expensive than those required by unpredicted failures. Improved maintenance could also support the planning of lifetime extensions of offshore wind farms, rendering them even more cost-effectively[15]. Furthermore, improving quality control lessens the risk of accidents which in turn could reduce insurance premiums.

Apart from developing robust individual sensing techniques, researchers and companies are working on multiple-sensor integrated systems with multi-parameter approaches to achieve better condition monitoring results[16]. Companies are also developing wireless sensor network systems, which could offer flexibility as well as reduce costs of installation and maintenance of the sensors[17]. Furthermore, LiDAR technology[18] is set to turn into the key wind measurement tool for offshore resource assessment and power curve verification[19].

The development of sensing and monitoring systems will favour drops on operation and maintenance costs of offshore wind turbines. This will result in an increase of clean energy at a competitive price, encouraging the use of alternative energy sources. In addition, it will contribute to accidents preventions in offshore farms. Moreover, research on integrated sensor systems will improve the general knowledge on new technologies, materials and wireless transmissions.

Under the current situation, such systems are pictured as an additional cost by some of the end users. Access to the structures, as well as difficulties encountered to

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[11] Wind Europe: Wind energy today data, available at: https://windeurope.org/about-wind/wind-energy-today/
[12] IEA-ETSAP and IRENA, (2016) "Wind Power- Technology Brief", Technology Brief E07- March 2016 available at: http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=1718
[13] Pliego A., García F., and Pinar JM., (2016) "Optimal Maintenance Management of Offshore Wind Farms" MDPI Energy Research, Engineering and Policy Journal. January 2016 available at: www.mpdi.com/journal/energies
[14] Shong F. (2017) "Offshore could set the standard in digitalizing the O&G value chain" Offshore Magazine Volume 77, Issue 4 available at: www.offshore-mag.com
[15] Espar M. (2015) youris.com "Innovative components pave way for cheaper wind energy." ScienceDaily, 28 May 2015. Available at: www.sciencedaily.com/releases/2015/05/150528083826.htm
[16] Risø National Laboratory for Sustainable Energy (2010) "Smart embedded sensor systems for offshore wind turbines." ScienceDaily. ScienceDaily, 19 January 2010 available at: www.sciencedaily.com/releases/2010/01/100114092404.htm
[17] O'Donnell D., Srbinovsky B., Murphy J., Popovici E. and Vikram Pakrashi, "Sensor Measurement Strategies for Monitoring Offshore Wind and Wave Energy Devices" Journal of Physics: Conference Series 628 (2015) 012117
[18] LIDAR (Light Detection and Ranging), is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. LiDAR technology can be used to accurately measure wind speeds and wind turbulence.
[19] OffshoreWind.biz (2017) " LiDARs Saving Millions on Costs, Experts Say" Available at: http://www.offshorewind.biz/2017/07/18/lidars-saving-millions-on-costs-experts-say/

demonstrate new technologies functionalities are additional burdens for the development of these products.

2.2 Relevance to grand societal challenges

The use of sensing and monitoring systems for offshore wind turbines will contribute to decreased maintenance and operation costs. It will also increase reliability and extend lifetime of offshore turbines. These objectives are in line with Horizon 2020 Work Programme 2016-2017 "Secure, Clean and Efficient Energy"[20]. The reduction of maintenance expenditure will result in an increase of clean energy at a competitive price helping reach a transition to a low carbon-carbon based society. In particular, sensing and monitoring systems would contribute to the two following societal challenges[21]:

- Secure, Clean and Efficient energy;

- Climate Action, Environment, Resource Efficiency and Raw Materials.

2.3 Market potential

While the use of sensing and monitoring systems is still in early stages of development, the opportunity to predict degradation, erosion, reduce accidents and cost of maintenance is expected to push the offshore industry to adopt these new technologies.

Wind power has undergone an immense growth, playing a central role as a renewable energy source in an increasing number of countries. The International Energy Agency (IEA) expects than 25% of the world's energy consumption will be coming from wind by 2035[22].

On one hand, 88% of offshore wind installations are located in European waters[23], meaning that Europe has been a frontrunner in developing this industry. Furthermore, offshore wind is expanding exponentially having reached a 5-year compound annual rate of 31%[24] and is expected to produce 7 to 11% of the EU's electricity demand by 2030[25]. The use of innovative sensing and monitoring systems could help lower maintenance investments further than expected, reaching an LCOE[26] of 54€/MWh and producing up to 25% of EU's electricity demand[27]. Therefore, a more competitive energy price will boost investments and could lead to an increase of capacity, wind farms and the introduction of new operators in the market.

On the other hand, the offshore industry is starting to rise in North America, East Asia and India, opening new markets for European companies to export technology and techniques. By 2040, global cumulative investment is set to reach 690b[28] EUR, presenting an opportunity for European players in the offshore market. Moreover, most

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[20] Based on: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/secure-clean-and-efficient-energy
[21] Based on: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges
[22] IEA (International Energy Agency) (2016) "World Energy Outlook 2016", available at: https://www.iea.org/newsroom/news/2016/november/world-energy-outlook-2016.html
[23] Global Wind Energy Council "Offshore wind power", available at: http://www.gwec.net/global-figures/global-offshore
[24] Ernest & Young (2015) "Offshore wind in Europe- Walking the tightrope to success"
[25] Hundleby G., Freeman K. (2017), "Unleashing Europe's offshore wind potential: A new resource assessment" Wind Europe and BVG associates
[26] Levelised cost of energy (LCOE)
[27] ibid
[28] IEA (International Energy Agency) (2014) "World Energy Investment Outlook, Special Report"- IEA/OECD, Paris

of O&M work is expected to be based on proactive repairs by 2045, presenting favourable circumstances to the uptake of predictive sensing and monitoring technologies[29].

2.4 Importance for the EU competitiveness

In the domain of sensing and monitoring systems for offshore wind turbines, Europe is leading in all parts of the value chain, including research and production. Europe is the largest market for sensing and monitoring systems for offshore wind turbines accounting 88% of global installations in its waters[30]. The start of governmental investments in other markets can threaten Europe's competitive position, if investments and continuous innovation are not keeping up in Europe.

As the offshore wind market as a whole is set to boom in the next decade, with its capacity tripling by 2024[31], O&M market is also projected to grow by 26% annually[32]. This represents an opportunity for European companies and regions that are currently leading the offshore wind market.

EU industry and governments have invested significant sums in R&D in order to build Europe's current competitive position in the offshore wind market. Over the past years, an overall investment of between about 850 million EUR and 1.7 billion EUR has been invested by the public sector in Europe. In particular, about 560 million EUR were invested by the European Commission. Furthermore, globally speaking, private financing doubles the amount compromised by the public sector[33].

[29] IRENA (2016), Innovation Outlook: Off shore Wind, International Renewable Energy Agency, Abu Dhabi
[30] ibid
[31] Ernest & Young (2015) "Offshore wind in Europe- Walking the tightrope to success"
[32] OffshoreWind.biz (2017) "Global Data: Offshore Wind O&M), available at: http://www.offshorewind.biz/2017/06/21/globaldata-offshore-to-contribute-18-4-to-wind-om-market-by-2025/
[33] IRENA (2016), "Innovation Outlook: Off shore Wind," International Renewable Energy Agency, Abu Dhabi

3. Value chain analysis

The current section addresses the value chain structure, key players, as well as the key identified constraints. The value chain can be considered as immature. The presented value chain is expected to develop as new materials are used to increase functionalities of the devices. The results of the analysis presented below illustrate that the key actors are concentrated across Europe. Although interaction across the value chain is present, visibility and interaction between newcomers and end users needs to be strengthened.

Sensing and monitoring systems do not represent a stand-alone industry. In order for the industry to function, it requires inputs from other industries to produce its products. The products generated could also serve as products for other industries.

3.1 Value chain structure

Figure 3-1 presents the reconstructed value chain structure for sensing and monitoring systems for offshore wind turbines, represented in three dimensions: (1) value-adding activities; (2) supply chain; and (3) supporting environment.

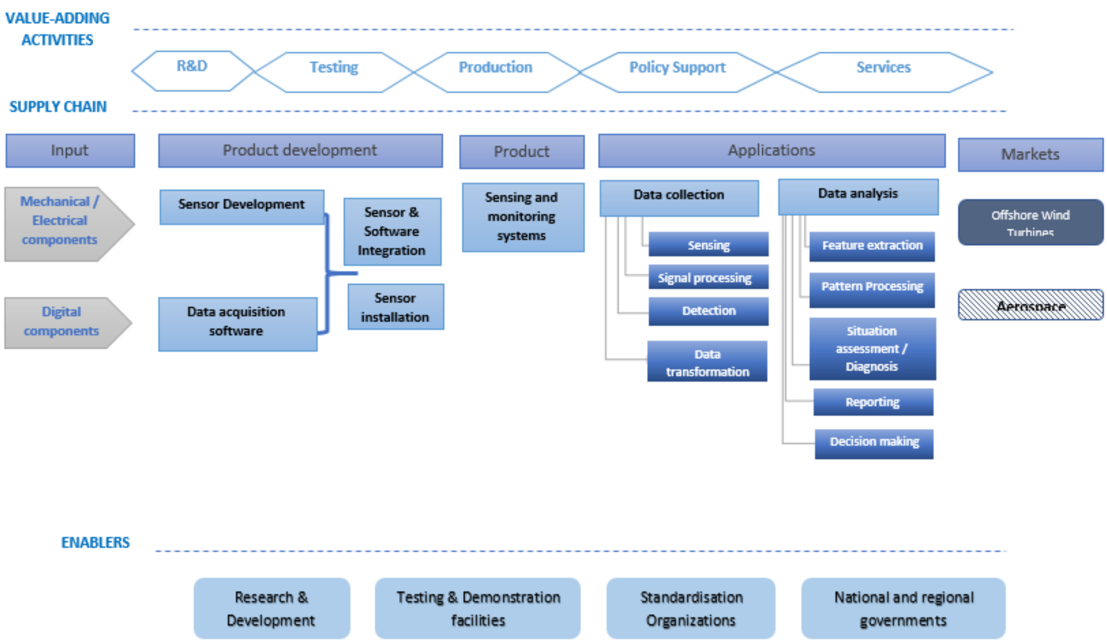

FIGURE 3-1: Value chain structure for sensing and monitoring systems for offshore wind turbines

The first dimension represents five co-related complementary value-adding activities, ranging from research & development to services. Although these activities are presented as a linear chain, in practice, however, they often are intertwined with multiple feedback loops embedded into the innovation trajectory. The ability to rapidly develop and evaluate sensor technology for its overall viability as a commercial device is crucial[34]. Aggressive development cycles can challenge the expertise of the developers. As the sets of expertise needed regarding new materials functionalities are different from those

[34] Maley S., Romanovsky R. (2012) "Sensors for Fossil Energy Applications in Harsh Environments" IMCS2012- 14th International Meeting on Chemical Sensors

required to design and fabricate a viable sensor. Developments regarding the wind turbines will determine the evolution of sensing and monitoring systems. At the same time, the progress of algorithms to clean data sets and identify patterns will be crucial to provide quality maintenance services. The testing activity is crucial for the commercialisation and promotion of new sensing and monitoring systems, as it provides valuable feedback to the researchers.

Partnerships and relations between all the actors across the value chain support the feeding to R&D, as well as, to the evolution of standards regarding safety and performance. Effectiveness of the devices also nourishes the new testing processes. Harsh environment sensing requires finding a balance between sensor protection and adequate exposure to the condition of interest. The key element is to identify the critical parts of the wind turbine that require monitoring and match them with the correct number of sensors.

The activities described in the second layer range from the mechanical and electrical component supply, used to produce sensors, to the actual monitoring activities carried out. The materials used for the development of the sensors take into account the harsh environment in which they will be deployed. Innovation and research are constant in order to employ new material which could increase the functionalities of the devices. Existing technologies allow the integration of software with the developed sensor, including the incorporation of advanced process control algorithms.

The supply chain also includes the design and set-up of the data collection, integration of sensor into one system, and the operation of the sensors. It also covers to identify analysis of the collected data problems and propose necessary actions[35]. The key steps are presented below:

- **Signal acquisition**[36]: sensors are dedicated to obtaining data from the offshore wind turbine. Collected data has to be roughly prepared, then filtered and analysed to take any information from the signals that is necessary for further study.
- **Detection**: data collected from sensors is analysed to determine if there are any abnormal signals that can inform about a problem. Special intelligent algorithms are used to allow efficient and correct detection of changes in the monitored data.
- **Diagnosis**: clearly determine the problem that has occurred. Use of a dedicated algorithm that can be based on artificial intelligence or a knowledge base generates a clear view on the state of health of the structures covered as well as analogue structures in neighbouring positions. Solutions can be then provided to solve identified problems.

Structuring and interpretation of the data set using algorithms is essential to monitor and be able to obtain timely, reliable information. As more experience is gained with the sensors in connection with wind turbines, it will be possible to use the sensors in other

[35] "Obrski P. (2014), "Developments in integration of advanced monitoring systems", International Journal Advance Manufacturing Technology – August 2014
[36] *Ibid*.

fields, such as aviation. Other uses could be in maritime applications or infrastructures such as bridges.

The third dimension represents actors that enable the sensing and monitoring systems for offshore wind turbines ecosystem. These enablers hold up the supply chain, from R&D institutions to organisations offering support to test the systems. SMEs and start-ups play a key role as they are willing to engage in more innovative research and take risks. Governments and standardisation organisations also support the supply chain.

3.2 Key players

The activities of the value chain are performed by different stakeholder groups, often with overlap among them. Most of the actors do not carry out one single activity, but cover multiple ones. Nonetheless, the number of value chain activities each stakeholder carries out may vary, depending on the need of each client. A significant exception are the suppliers of components who usually limit themselves to supplying different components for manufacturing the sensors without being involved in other industrial applications.

The following actors were identified for the European value chain on sensing and monitoring systems for offshore wind turbines:

- **Research and development centres**: active actors in R&D related to sensing and monitoring systems (sensor development, new materials, functionalities, algorithms, integrated sensors to carry out tasks simultaneously). Research organisations and universities do not limit their activities within the value chain to innovative research. They also offer testing and prototyping.
- **Sensor manufacturers**: the sector is quite diverse and consists mainly of small enterprises. They make use of various components provided by a number of suppliers with the input of highly skilled labour. Some of these companies tend to expand their activities further and are also involved in the integration and analysis of data activities.
- **Operation and maintenance companies**: these companies usually take the task of bridging the gap between sensor manufacturers and end-users. They are also deeply involved in research and development, but with a more business-oriented approach than R&D institutions. Service providers are often the owners and integrators of the platform and sensors. Therefore, they usually take the role of sensor integrator. They usually do the methodical design of the data collection process, and participate in its transformation and analysis. Usually the wind farm owner enters into service agreements with the turbine manufacturer regarding its maintenance.
- **Software developers:** these companies represent interface/software producers specialising in software development for bid data analysis. Although there is a community of companies developing monitoring software, most of the companies developing the sensors are also developing the software and algorithms to use.
- **End users**: these refer to **Windfarm operators** who use the sensing and monitoring systems to predict the degradation of their offshore wind turbines. The end user group is the one to set the requirements for the monitoring activity which in turn are driven by the aim of the monitoring exercise which can be research driven, part of industrial optimisation or a legal obligation. Large companies such

as VIG are developing their own sensing and monitoring systems and are present through the whole value chain.

The value chain is a mix of big companies, start-ups and SMEs, working in flexible networks and alliances.

The table below showcases some examples of the organisations, start-ups, SMEs and large companies involved in the sensing and monitoring systems for offshore wind turbines value chain. Some of the listed companies have headquarters outside the EU; nevertheless, these companies were also included due to their active presence on the European market. The list should by no means be considered exhaustive.

TABLE 3-1: Key players of the value chain

	Research & Development	Testing	Production	Policy Support	Services
Research & development / Testing facilities	Fraunhofer IWES (Germany) Riso DTU (Denmark) CENER (Spain) University of Oldenburg (Germany) Ingenium Research Group (Spain) Kiel Univeristy of Applied Science (Germany) Foundation Offshore Wind Energy (Germany) OWI-Lab (Belgium) Offshore Renewable Energy Catapult (UK) WMC (The Netherlands) ECN (The Netherlands) Edinburg University (UK) FORCE Technology (Denmark) TECNALIA (Spain)	WINDBOX (Spain) Fraunhofer IWES (Germany) CENER (Spain) OWI-Lab (Belgium) Offshore Renewable Energy Catapult (UK) WMC (The Netherlands) ECN (The Netherlands) FORCE Technology (Denmark) Energy Technologies Institute (UK)	Foundation Offshore Wind Energy (Germany)	CENER (Spain) Foundation Offshore Wind Energy (Germany) Energy Technologies Institute (UK)	Riso DTU (Denmark) CENER (Spain) Foundation Offshore Wind Energy (Germany) OWI-Lab (Belgium) Offshore Renewable Energy Catapult (UK) ECN (The Netherlands) DNV GL (Norway) FORCE Technology (Denmark) Ecowind cluster TECNALIA (Spain) Energy Technologies Institute (UK)

	Research & Development	Testing	Production	Policy Support	Services
Sensors manufacturers / Measurement Systems	Zensor (Belgium) HBM (Germany) Eologix (Austria) Nortek (Norway) FBGS (Belgium) 2EN (Greece) Ammonit Measurements GmbH(Germany) Ampacimon (Belgium) Automasjon and Data AS (Norway) Kintech Engineering (Spain) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Nortek (Norway)TECNALIA (Spain)	WINDBOX (Spain) Fraunhofer IWES (Germany)CENER (Spain) OWI-Lab (Belgium) Offshore Renewable Energy Catapult (UK) WMC (The Netherlands) ECN (The Netherlands) FORCE Technology (Denmark)	Zensor (Belgium) HBM (Germany) Eologix (Austria) Nortek (Norway) FBGS (Belgium) 2EN (Greece) Ammonit Measurements GmbH(Germany) Ampacimon (Belgium) Automasjon and Data AS (Norway) Kintech Engineering (Spain) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Nortek (Norway)		Zensor (Belgium) Nortek (Norway) Kintech Engineering (Spain) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Nortek (Norway)
Operation and maintenance companies / Data analysis	DNV-GL (Norway) Bachmann (Austria) Wölfel(Germany) HBM (Germany) Zensor (Belgium) DEWI (Germany) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Automasjon and Data AS (Norway) FORCE Technology (Denmark) TECNALIA (Spain)		Bachmann (Austria) DNV-GL (Norway) Wölfel(Germany) HBM (Germany) Zensor (Belgium) DEWI (Germany) Adwen (France) ABO Wind (Germany) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Automasjon and Data AS (Norway)		DNV-GL (Norway) Bachmann (Austria) Wölfel(Germany) HBM (Germany) Zensor (Belgium) DEWI (Germany) DEME (Belgium) ABO Wind (Germany) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain) Automasjon and Data AS (Norway) FORCE Technology (Denmark)
Software developers	Nortek (Norway) HBM (Germany) Bachmann (Austria) Zensor (Belgium) Uptime Engineering (Austria) 2EN (Greece) ATM PRO (Belgium) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain)	WINDBOX (Spain) Fraunhofer IWES (Germany) CENER (Spain) OWI-Lab (Belgium) Offshore Renewable Energy Catapult (UK) WMC (The Netherlands) ECN (The Netherlands)	Nortek (Norway) HBM (Germany) Bachmann (Austria) Zensor (Belgium) Wind and Economy (Germany) Uptime Engineering (Austria) 2EN (Greece) ATM PRO (Belgium) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain)		Nortek (Norway) HBM (Germany) Bachmann (Austria) Zensor (Belgium) Wind and Economy (Germany) DNV-GL (Norway) Siemens AG (Germany) GE Renewable Energy Iberdrola (Spain)

The value chain players are often interacting with each other through Joint Industry projects (JIPs) Partnerships and projects, such as INTELWIND[37], HEMOW[38], EERA-DTOC[39], Com4Offshore[40], DEEPWIND[41] or Energy Technologies Institute[42] . Nevertheless, newcomers face difficulties to interact with well-established players. Collaborative research partnerships and Industry projects work well to meet shared challenges and promote long-term cooperation between supply chain actors. A good example of collaboration is the EU-funded LEANWIND project on logistics and supply chain optimisation, using LEAN business principles. Another example is ECOWindS (The European Clusters for Offshore Wind Servicing) which builds on existing networks within offshore wind energy to establish cluster cooperation in Offshore Wind Servicing (OWS).

3.3 Key constraints

Several key constraints have been identified in the value chain for sensing and monitoring activities for offshore wind turbines value chain.

- **New disruptive systems encounter difficulties to go beyond prototype stage:** Europe has a leading position in R&D and has built a leadership position in the offshore wind market.[43] Although there is a trend to apply the knowledge acquired on onshore and offshore oil and gas sector, the rapid evolution of the wind turbine characteristics implies that many new products only reach the prototype stage as they need to adapt quickly to new trends and materials. Moreover, even if Europe has also a strong position regarding production of sensing and monitoring systems, small companies can encounter difficulties certifying and gaining access to demonstration sites, which means that new innovative sensors have trouble reaching the end market.
- **Access to real conditions testing facilities:** the development of the European sensing and monitoring industry depends on the level of awareness of the capacity of the systems to reduce the cost of the operation and maintenance activities. The new systems need to be robust, and prove their effectiveness. Some small companies have difficulties convincing end users of the benefits of using these new systems. Some stakeholders have expressed their concerns about the difficulties to access demonstration facilities, as well as, the difficulties to test the new systems in real conditions.
- **Lack of visibility for small players:** newcomers and small actors encounter burdens to interact with bigger player and could be left outside the market.
- **Value chain players need to be more integrated:** end customers often lack resources to integrate all the components, or are not capable of reaching the relevant companies. Big stakeholders are present all through the value chain,

[37] INTELWIND (Development of an intelligent condition monitoring system for application on critical rotating components of industrial-scale wind turbines) project funded under FP7

[38] HEMOW (Health Monitoring of Offshore Wind Farms), project funded under FP7-People http://www.hemow.eu/

[39] EERA-DTOC (European Energy Research Alliance- Design Tools for Offshore wind farm Clusters) funded under FP7-Energy http://www.eera-dtoc.eu/

[40] Com4Offshore (Interactive Communication and Monitoring System for Offshore Wind Energy) http://www.com4offshore.com/

[41] DEEPWIND (Future Deep-Sea Wind Turbine Technologies) project funded under FP7-Energy http://www.deepwind.eu/

[42] Energy Technologies Institute is a public-private partnership between global energy and engineering companies and the UK Government http://www.eti.co.uk/

[43] Ernest & Young (2015) “Offshore wind in Europe- Walking the tightrope to success”

meaning they are able to develop and integrate all the components. This means they include their own technology and know-how, but often left aside players that could enhance the operability and the characteristics of the systems.

- **High costs related to some sensing systems outweigh the benefits to O&M costs:** sensing and monitoring systems are not cheap; the use of novel materials for the sensors, the integration, software components and analysis of the data makes the use of these type of systems expensive. Improvements regarding the cost benefit analysis of the new systems, the number of sensors needed to monitor critical parts of the wind turbine and de-risking the adoption of new technologies are essential for the development of the sector.
- **Data is not being used to its full potential:** part of the data obtained through the sensing and monitoring systems is not being interpreted. To move from numbers to insights is arduous. Sometimes, companies do not have right skilled workers to analyse it.

4. Analysis of the EU competitive positioning

The current section elaborates on the strengths and potential of the EU regions, key risks and challenges, as well as the opportunities for the EU regions. The consulted stakeholders report that the whole value chain for sensing and monitoring systems for offshore wind turbines can be covered by European players.

4.1 Strengths and potential of the EU regions

In this sub-section, we address the expected Europe's global position in 2030, key competitive advantages of Europe, as well as regions that could be in the lead.

The current and future global position

The development of the sensing and monitoring systems for offshore wind turbines is closely linked to the offshore wind turbine industry. Europe is currently leading the offshore wind energy market and is expected to triple its capacity by 2020[44]. Furthermore, 88% of the offshore wind installations are located in Europe[45].

European governments and private companies have been invested significant sums in R&D and have help built a leadership position on the offshore wind market[46]. Whereas investment in onshore wind has dropped recently, investment in offshore wind is following a growing tendency to a net increase of 39% in 2016[47].

The European industry has taken advantage of the knowledge from onshore wind and offshore oil and gas sectors and is adapting it to use it in offshore wind[48]. Frontrunners of this development have been the UK, which account 55.9% of Europe's capacity, Denmark (15.8%), and Germany (13%)[49].

Although Europe is leading the development regarding offshore wind industry, it remains an emerging market and needs to optimise its operation and maintenance costs in order to become competitive[50]. New sensing and monitoring systems are being rapidly developed, as they are considered to be a key tool to improve economic efficiency and render wind power facilities cost-efficient. As penetration of offshore wind increases, the necessary transmission and interconnection will need to be implemented. These prospects will push to develop further the European industry.

According to stakeholders, the whole value chain is covered by European companies. There are enough actors in the market, being able to take large production volumes. Investment and support to keep the technology innovation trend should be a key priority, in order to retain Europe's competitive advantage.

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[44] Ernest & Young (2015) "Offshore wind in Europe- Walking the tightrope to success"
[45] Global Wind Energy Council "Offshore wind power", available at: http://www.gwec.net/global-figures/global-offshore
[46] Europe Commission has invested €565 million into projects supporting offshore wind via EERP funds- data retrieved from Offshore wind in Europe: Walking the tightrope to success
[47] Wind Europe (2017) "Wind in power: 2016: European statistics" available at: https://windeurope.org/about-wind/statistics/european/wind-in-power-2016/
[48] IRENA (2016), Innovation Outlook: Off shore Wind, International Renewable Energy Agency, Abu Dhabi
[49] Ernest & Young (2015) "Offshore wind in Europe- Walking the tightrope to success"
[50] IRENA (2016), Wind Power Technology Brief, International Renewable Energy Agency, Aby Dhabi

Although European players are in the lead, increase of attention from other markets can put at risk Europe's leading role. Asia in particular offers a large potential for the offshore wind industry, and several countries, including China, Japan, South Korea, India and Taiwan are developing ambitious plans for offshore wind infrastructures. This can represent both an opportunity and a risk. European industry can grow and enter new markets. However, lower production costs in some countries can represent a threat. Therefore, attention must be paid to avoid being overtaken by innovation in other countries.

As sensing and monitoring systems are still evolving and the supply chain is developing, there is scope for new companies to enter the sector, and drive in operation and maintenance cost reductions. It is expected that by 2045, most of O&M work will be based on proactive repairs due to the used of predictive sensing and monitoring technologies[51].

Consulted stakeholders are persuaded that Europe can keep playing a leading role in the offshore wind market and drive innovation regarding O&M.

Key competitive advantage of Europe

Europe provides the right environment for the development of innovative sensing and monitoring systems for offshore wind turbines. The key competitive advantages include the following:

- Connection to a wide variety of actors and resources;
- Stable innovation driven ecosystems;
- Knowledge of and experience with research, product development and prototyping in this domain;
- Innovativeness of value chain actors;
- Collaboration among all typical actors in the value chain;
- Support from public authorities at all policy levels;
- Large potential market.

Regions that could be in the lead

Stakeholders indicate that value chain activities are spread across diverse EU regions. Nonetheless, Germany, Austria and Denmark are key actors regarding sensor manufacturing and data acquisition, while integration of components is led by Germany, Flanders and Norway. Spain, Portugal, Belgium and Italy are also active players[52]. Countries such as Germany, Denmark, UK, Ireland, France, Sweden, Finland and The Netherlands have the largest technical potential capacity[53].

The Vanguard Initiative Pilot Project on ADMA energy was launched in June 2014 with the objective to make the EU a global leader in manufacturing robust high integrity components for marine renewables and offshore energy applications. In particular, the Pilot aims to help medium and large(r) companies strengthen their supply chains by

[51] IRENA (2016), Innovation Outlook: Off shore Wind, International Renewable Energy Agency, Abu Dhabi
[52] Based on interview data
[53] Hundleby G., Freeman K. (2017): "Unleashing Europe's offshore wind potential" Wind Europe & BVG Associates June 2017

working with innovative SMEs and provide smaller companies with new, high-demand customers to grow their business. The initiative is led by the Basque Country and Scotland with the participation of 11 other European regions: Asturias, Andalucía, Dalarna, Emilia-Romagna, Flanders, Lombardia, Navarra, Norte, Ostrobothnia, Skane and Syddanmark[54].

At the national level, publicly funded, centres and institutions supporting offshore wind activities include Basque Energy Cluster, Spain's National Renewable Energy Centre (CENER), Fraunhofer IWES, Lindoe Offshore Renewables Centre (LORC) and Offshore Renewable Energy (ORE) Catapult.

4.2 Key risks and challenges

The risk and challenges include:

- **High sensor costs**: materials and technologies leading to efficient sensing and monitoring systems are pricy. The value of these technologies may discourage the implementation of disruptive technologies. There is a need to strike a balance between the number of sensors to be used to monitor the critical parts of offshore wind turbines, their price and the impact in O&M cost reduction.
- **Regulatory gap**: it is not compulsory to include operation and maintenance systems at the EU level. National requirements regarding sensing and monitoring technologies and standards are diverse. For instance, in Germany the BSH requires that at least 10% of offshore structures use CMS monitoring. Fragmentation and lack of business convergence on standards, as well as, uncertainty regarding national requirements could be a burden to European predominance. The introduction of European guidelines and common standards regarding monitoring activities could help the adoption of disruptive technologies. A common vision regarding standards and guidelines should be encouraged. A European initiative would help to foster competitiveness, and harmonisation of requirements, as well as, avoid duplicities of efforts and resources from the companies.
- **Skills gap**: specialised labour force with good technical command of the issues at stake is necessary through all the value chain. There are instances in which finding employees with the right skills to perform some specialised parts of the work, in particular regarding data interpretation, is challenging. There is also a need to train multidisciplinary professionals on emerging technological developments.
- **Hesitation to adopt disruptive technologies**. taking up new sensing and monitoring systems heavily dependent on the companies' capacity to convince end users of the benefits of these technologies. Proving their ability to cost-effectively predict damage is essential to gain the trust of stakeholders.
- **Potential complications for small companies and new comers:** some new player and small companies are facing problems to engage collaborations with well-established actors of the value chain. Moreover, leading turbine manufacturers often prefer to develop in-house innovation through the whole

[54] Available at: http://www.s3vanguardinitiative.eu/cooperations/making-eu-global-leader-components-marine-renewables-and-offshore-energy-applications

value chain in order to avoid exposure of know-how which could benefit competitors.

4.3 Opportunities for the EU regions

The development of sensing and monitoring systems for offshore wind turbines will bring opportunities for the regional key players.

As it has been mentioned, European regions are currently leading the offshore wind market. As offshore capacity increases in the upcoming years, the urge to diminish O&M will push the introduction of sophisticated sensing and monitoring systems in order to minimise maintenance interventions. A growing demand will boost employment and competitiveness in the sector, attracting new companies. Therefore, there is a considerable potential for regional and European development in this market due to its strategic importance in the expansion of the offshore wind energy production.

In addition, deployment of offshore wind farms outside the European market represent an opportunity for European companies to grow and position themselves in the global arena. To fully benefit from the potential of this sector, there is a need for open cooperation amongst companies and regions. Setting-up a clear framework for IP and data sharing will help boost confidence and trust to establish new partnerships. Taking into consideration the EU’s regional strengths and potential, there is a need to build strong partnerships. Furthermore, awareness raising campaigns amongst end users regarding the benefits of taking up new systems should ensure acceleration in the use of new technologies.

5. Policy implications

The current section aims to present specific policy recommendations on what needs to be done in order to strengthen the EU competitive position regarding this product in the coming years, and specifically on how to enable European industry to move to the higher end of the value chain. We elaborate on measures with both the immediate and longer-term focus.

5.1 Measures with immediate focus

The following measures with immediate focus have been identified:

- **EU-coordinated actions focused on cooperation**. Europe is leading the development of the offshore wind industry, and possesses the necessary know how to develop even further and overtake new markets. Although, stakeholders have mentioned that all the technology components are based in Europe, cooperation amongst actors is still facing some constraints. New players are facing difficulties to collaborate with well-established and biggest players. As outlined in the previous section, one of the key barriers is the reluctance of end users to trust new comers. Moreover, partnerships and collaborations usually engage the same participants. Major players tend to interact with the research community rather than interacting with competitors. Greater competition should be considered as a driver to ensure efficiency, strengthen synergies between stakeholders and diminish operation and maintenance costs. New partnerships and trans-regional cooperation should be boosted, in particular in the fields of research and technological development. A visible pipeline of projects to strengthen and encourage new partnerships and facilitating shared learning should be contemplated. The Smart Specialisation Strategy Platform[55] and the Vanguard Initiative[56] are good examples of effective and result-driven cooperation.
- **Improve access to the market for disruptive offshore sensing and monitoring activities**. The use of new techniques and technologies to improve the O&M of offshore wind turbine might result to be cost risky for end users. Some developers could be reluctant towards introducing innovative techniques which are brought by newer offshore wind players seeking to disrupt the market[57]. Policymakers should focus on supporting mechanisms to drive competition and de-risk customers for using novel technologies, for instance by supporting successful project delivery, demonstration and real implementation of technologies. R&D funds should take into account the impact of the innovation on the LCOE[58] as well as the possibility of commercialising. Furthermore, actions to connect innovators with industry users should also be encouraged.
- **Expanding the access of demonstration and testing facilities.** Pilot projects and testing facilities should be made more accessible for new companies to test their newly developed products. A challenge faced by some actors is the need to

[55] Available at: http://s3platform.jrc.ec.europa.eu/adma-energy
[56] Available at: http://www.s3vanguardinitiative.eu/cooperations/making-eu-global-leader-components-marine-renewables-and-offshore-energy-applications
[57] Based on interview data.
[58] Levelised cost of energy (LCOE)

demonstrate a proven track record of new developments or even modifications to existing products, as investors regard them to constitute a financial risk. Public financial support to demonstration projects and testing facilities will ensure that all actors across the value chain can test and demonstrate new development without a need of uncertain investments from end-users. Having close access to testing facilities can attract new players to the market, improving innovation, enhancing synergies and reducing the financial risk for end users. Due to the difficult conditions faced by offshore wind turbines, the possibility of assessing these techniques in real condition environments should be encouraged[59].

- **Developing the EU standards**. It may be helpful to encourage wind farm-wide control strategies, as at the moment O&M of offshore wind farms is not compulsory at EU level. The introduction of guidelines regarding O&M technologies could help foster the use of these new innovations by operators. Furthermore, the adoption of EU guidelines regarding monitoring systems could be used as an opportunity to enhance efficiency and simplify permission procedures for offshore wind farms. As a continuance follow up would help manage the risk of offshore wind project[60]. There is a need for national regulatory and certification bodies to work in concert and establish good practice and common standards.

5.2 Measures with longer-term focus

The following measures with longer-term focus have been identified:

- **Enhancing skills:** There is a need to support training activities and form multidisciplinary professionals able to adapt to the fast-changing technological environment. In particular some stakeholders have mentioned the need to develop data interpretation skills. Skills related to unveiling the story behind the information obtained through the sensing and monitoring systems are essential. In order to address this issue, the European Commission recently launched the blueprint on sectoral cooperation on skills in the maritime technology sector[61].
- **Financial incentives**: funding should strengthen collaborative research and networks. Further funding instrument should target the end user directly. For instance, the implementation of guarantee instruments might facilitate private sector involvement and improve the financing and the adoption of sensing and monitoring systems by significantly reducing the risk for investors. Additional funding instruments should connect innovators with industrial end-users.
- **Ensure stable support to wind energy**: with a young industry in its quest to remain market leader and achieve cost competitiveness, the EU should encourage ambitious plans, with strong incentives that signal long-term certainty and promote regional approach. There is a need to strengthen open platforms and joint industry projects (JIPs) to ensure uptake of new sensing and monitoring techniques.

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[59] Based on interview data.
[60] Based on interview data.
[61] Blueprint for Sectoral Cooperation on Skills: maritime technologies. Responding to skills mismatches at sectoral level. 2017 DOI: 10.2767/17064 https://ec.europa.eu/maritimeaffairs/policy/skills-career-development_en

Annex A: List of interviewees

Table A-1: Overview of the interviewed stakeholders

Nr	Name	Position	Organisation	Country	Stakeholder type
1	Yves Van Ingelgem	CEO	Zensor	Belgium	Startup-Sensor Development
2	Yerun Fernandez Heijnen	Service Line Leader Measurements, Renewables Advisory	DNVL GL Energy	Norway	Large Company
3	Cristina Oyón	Head of Strategic Initiatives	SPRI	Spain	Regional Government
4	Søren Granskov	Sales Manager Materials, Engineering and Compliance	FORCE Technology	Denmark	Large Company
5	Stuart Bradley	Offshore Renewable Strategy Manager	Energy Technologies Institute	UK	PPP

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