Renewable and Sustainable Energy Reviews 81 (2018) 2672–2683

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The North Sea Offshore Wind Service Industry: Status, perspectives and a joint action plan

Per Dannemand Andersen[a,*], Niels-Erik Clausen[b], Tom Cronin[b], Kalle A. Piirainen[a,c]

[a] DTU Management Engineering, Technical University of Denmark, Diplomvej 372, DK-2800 Kongens Lyngby, Denmark
[b] DTU Wind Energy, Technical University of Denmark, Frederiksborgvej 399, Building 115, DK-4000 Roskilde, Denmark
[c] Lappeenranta University of Technology, Skinnarilankatu 34, 53850 Lappeenranta, Finland

ARTICLE INFO

Keywords:
Offshore wind
Service
North Sea
Innovation System
Foresight
Action Plan

ABSTRACT

The Offshore Wind Service sector is about to established itself as an industrial sector with an own identity, own organisation, and with large future challenges. The article introduces this new sector, including assessment of present and future market sizes. The overall aim of the research reported in this article was to increase the innovation capacity of the European offshore wind servicing (OWS) sector by establishing cross-regional cooperation and intensifying the relationship between research and the offshore wind industry. The article uses the concept of innovation system foresight (ISF). The linking of the two concepts of foresight and innovation systems has been explored by several studies, but ISF takes a further integration of the two concepts. The article presents a set of concrete actions at multiple levels to support the development of the offshore wind service sector. The findings provides an input for a concerted effort for supporting both the offshore wind development and the emerging clusters of offshore wind services around the North Sea. In addition, the article addresses the value of the ISF approach to such policy development.

1. Introduction

As Europe is working its way towards a low carbon future as laid out in the European Strategic Energy Technology Plan (SET-Plan) [1], the importance of renewable energy sources is growing. In particular, there are high expectations of the role of offshore wind, and the installed capacity is projected to increase significantly towards 2020 and beyond [2,3]. However, offshore wind energy is relatively expensive as measured by Levelized Cost of Energy (LCoE), and thus the industry has outlined an ambitious goal of reducing the cost of offshore wind by 40% by 2020 compared by the average LCoE by 2012 [4].

While capital expenditure of major components and other up-front costs play a major role in LCoE, the services for project development installation, operations and maintenance (O & M) contribute up to 46% of LCoE (capital and operating expenditure, CAPEX and OPEX). O & M services' contribution alone is estimated between 25% and 28% [5–7]. From these numbers, it is apparent that while much attention is rightly paid to the development of the physical components for offshore wind farms and the associated technologies, the services associated with offshore wind farms hold potential for cost reduction as well. Furthermore, the North Sea is currently the most important site for offshore wind installations, and industry clusters based on Offshore Wind Services (OWS) are emerging in regions around the North Sea.

Recently, several studies have analysed the North Sea offshore wind innovation system [8–10]. Among the conclusions is that there is a need for concentrated action to improve the function of the European offshore wind innovation system [9]. However, an orchestration of the interests, stakeholders and policies of countries involved in a European offshore wind innovation system is difficult. Hence, the aim of this article is partly to report on the results of the project European Clusters for Offshore Wind Servicing (ECOWindS) funded by the European Union's Regions programme. The project focussed on the

Abbreviations: CAPEX, Capital expense; ECOWindS, European Clusters for Offshore Wind Servicing; EERA, European Energy Research Alliance; EWEA, European Wind Energy Association's; GW, Gigawatts(-s); GWO, Global Wind Organization; HSEQ, Health, safety, environmental and quality; ISF, Innovation System Foresight; JAP, Joint Action Plan; LCoE, Levelized Cost of Energy; MW, Megawatt(-s); OH & S, Occupational Health and Safety; O & M, operations and maintenance; OPEX, Operating expense; OWS, Offshore Wind Services; RDI, Research, Development, and Innovation; SET-Plan, European Strategic Energy Technology Plan; STEPLED, Social, Technological, Economic, Political, Legal, Environmental, Educational and Demographic factors; SWOT, Strengths and Weaknesses, and Opportunities and Threats; TIS, Technological Innovation Systems; TSO, Transmission System Operator; TPWind, European Wind Energy Technology Platform; UK, The United Kingdom of Great Britain and Northern Ireland; WAB, Windenergie Agentur Bremen-Bremerhaven

* Corresponding author.
E-mail address: pean@dtu.dk (P.D. Andersen).

http://dx.doi.org/10.1016/j.rser.2017.06.073
Received 28 November 2016; Received in revised form 30 May 2017; Accepted 22 June 2017
Available online 03 July 2017
1364-0321/

engineering part of off shore wind servicing, and did not consider financial services, planning or other non-engineering parts of wind servicing. The work presented in this article is one of the results of ECOWindS. The project was funded by the European REGIONS program: Transnational cooperation between regional research-driven clusters. ECOWindS was a collaboration between research-driven clusters within offshore wind servicing in four regions around the North Sea.

One of the key goals and tangible outcomes of the ECOWindS project was a 'Joint Action Plan' (JAP). The JAP is essentially a roadmap for OWS. It comprises a portfolio of actions that include direct and indirect research, development, and innovation (RDI) activities, including network and capacity building, development of test sites and standards. In the broader ecosystem of offshore wind there are existing strategic research agendas and roadmaps [4,11–13], however they do not address offshore wind *services* thus there was a felt need to develop the JAP to support specifically OWS-relevant RDI.

The theoretical framework for this study builds on the Technological Innovation Systems (TIS) and the associated functions perspective. A TIS can be defined as a set of networks of actors institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product [14]. A key proposition in the literature is that there are key functions that enable the development of a TIS, and if the functions are strong and 'work properly', the innovation system develops and grows [9,15,16]. Usually, seven such functions are used in the analyses: 1) Experiments by entrepreneurs, 2) Knowledge development, 3) Knowledge exchange, 4) Guidance for search, 5) Market formation, 6) Resource mobilisation, and 7) Creation of legitimacy. A detailed discussion of these functions can be found elsewhere [16,17]. Furthermore, this article uses the concept of Innovation System Foresight (ISF) that combines the concept of foresight with the innovation systems approach (Andersen & Andersen 2014; Andersen et al., 2014). Innovation Systems Foresight (ISF) is defined as a systemic, systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint actions to improve innovation system performance with the ultimate goal of improving desirable socio-economic performance [18].

The rest of the article is organized as follows. The second section lays out the theoretical framework for the analysis. The third section explains the methodology for ISF in this instance. The fourth section reviews the OWS innovation system around the North Sea. The fifth section proposes actions for strengthening the innovation system. The article closes in the sixth section with discussion and conclusions.

2. Innovation system foresight

The EcoWindS project must be seen in the perspective of the concept of regional Smart Specialization, which aims to support the European Cohesion target by enabling regions to identify their relative strengths and leverage them, while avoiding imitation or duplication and head-on competition with other regions [19]. The concept of smart specialization was first introduced in 2008 by an expert group of academics (Knowledge for Growth, K4G) that was established by the European Commission to revive the European Union's Lisbon Strategy [20,21]. The concept was rapidly adopted at the highest level of policy and became one of the key stones in the EU2020 strategy. However, the fast adoption of the concept has to a wide extent taken place without a solid theoretical and empirical foundation, and smart specialization strategies are criticised for being more based on hopes than empirical facts [20,22–24].

As mentioned in the introduction this article built on the theoretical concept of innovation system foresight (ISF) [18,25,26]. The nexus between foresight and innovation systems has been explored by some studies and until recently there seems to be only a little communication between the innovation system research and foresight [27]. Most studies have focused on how foresight can contribute to innovation system analysis [28–31]. Others have explored practical applications of an integrated framework of innovation system analysis and foresight [32]. The innovation system foresight takes a further integration of the two fields of research.

First, most of the studies that focus on how foresight can contribute to innovation system policies adopt a predictive understanding of the future. Previous studies note that there is a strong need for assessing future development paths in innovation in order to develop effective innovation policy strategies [31,33]. However, forward looking (predicting, forecasting, and explorative) is only one approach to foresight. The other is normative (anticipative, backcasting) [34,35]. ISF emphasises understanding the evolutionary path of a given system in its context and the processes that drive that development, borrowing from the field of innovation studies in conception of innovation systems and their evolution [18,26,36,37]. There are some assumptions that come with this orientation. First and foremost, foresight and its implications and recommendations are context dependent [38–40]. It follows that foresight needs to include an analysis of the context and forces that drive the development, an explanation of the system [37], to offer evidenced recommendations for innovation policy. Traditionally foresight has had a limited impact to decision making [27], and one of the key reasons is that to process and outputs do not serve the needs of the stakeholders of the system [41,42]. ISF by definition addresses this by including a comprehensive analysis of the system and context to arrive to conclusions about its foreseeable development.

3. Methodology

The project ECOWindS project can be characterized as an ISF process [18,25]. The ECOWindS project ran from November 2013 to October 2015. During that time, the process had three main phases, each of which contained sub-phases (see Fig. 1). The planning phase comprised preparation and organisation of the foresight exercise. The main phase was the most comprehensive, as well as the most time-consuming and labour-intensive part of the foresight process. It is in this phase that the regional advantages were analysed, visions and objectives were set and prioritized, and actions were planned. The main phase was divided into four sub-phases: mapping, foresighting, prioritising and planning. The follow-up phase comprised two sub-phases: dissemination and learning.

3.1. Planning and organising the project

The planning and organisation phases of the EcoWindS project primarily took place in the formulation of the project. The project was funded by the European Union's Framework Programme 7's CAPACITIES programme: Regions of Knowledge. The overall aim of the Regions of Knowledge programme was to strengthening the research potential of European regions, in particular by encouraging and supporting regional 'research-driven clusters' associating universities, research centres, enterprises, regional authorities and other stakeholders across Europe. The total budget was EUR 1,757,714. The duration of the project was 3 years: November 2013 to October 2015.

The partner regions were: South Denmark (Region South Denmark), East of England (East Anglia, Counties of Cambridge, Suffolk and Norfolk), North West Germany (Bremen-Bremerhaven region, federal states [Bundesländer] of Bremen, Hamburg, and Niedersachsen, and as an

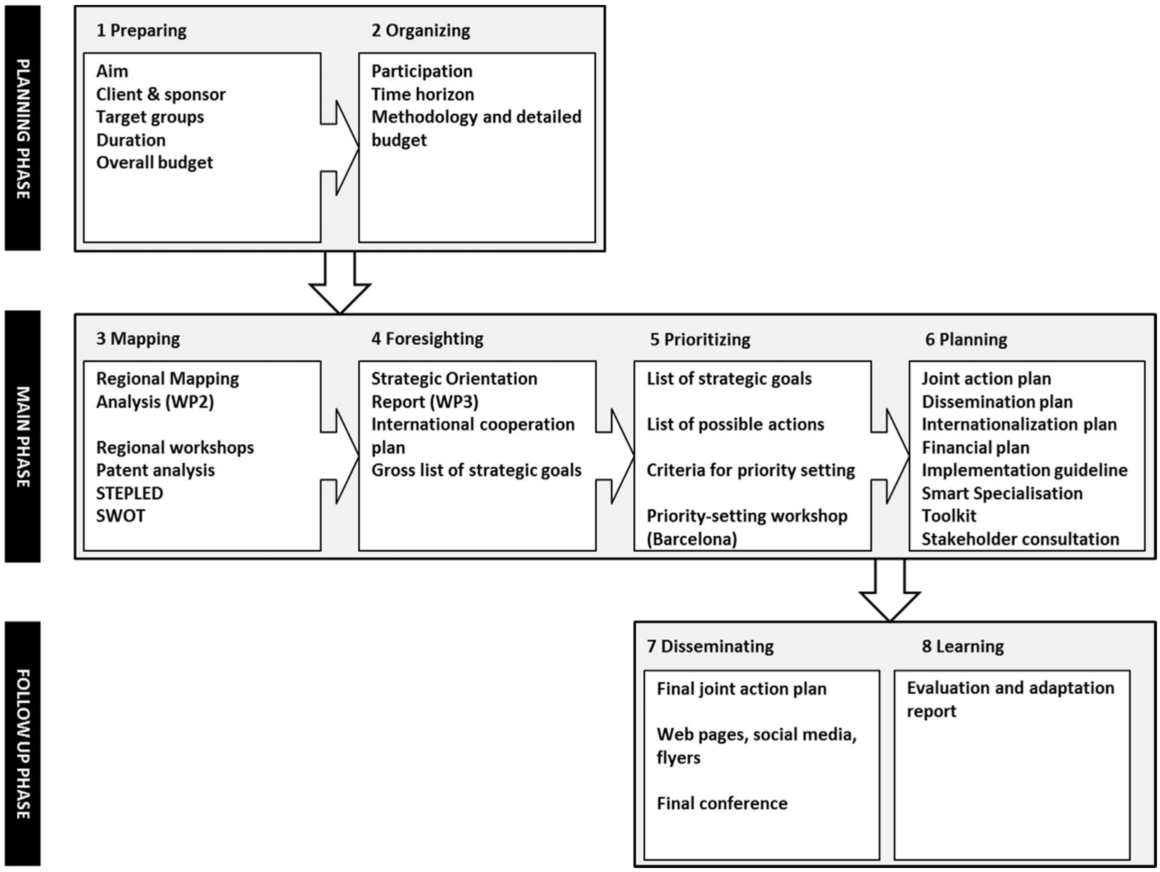


Fig. 1. The EcoWindS process in an adapted foresight framework [18]

extended region Schleswig-Holstein, Mecklenburg-Vorpommern and Nordrhein-Westfalen as well) and Møre in West Norway. The overall aim of the project was to increase the innovation capacity of the European offshore wind servicing (OWS) sector by establishing cross-regional cooperation and intensifying the relationship between research and the offshore wind industry. A further aim was to contribute to reduction of offshore wind power cost, and by extension European competitiveness and achieving the SET Plan [1] goals for renewable energy generation. During the project, it emerged that the overarching specific goal was, aligned with the European Wind Energy Association's (EWEA) 2020 target, a 40% reduction of LCoE by 2020. The same target is also mentioned by the Crown Estate [4].

The core participants in the project were offshore cluster organisations in the four regions (Offshoreenergy.dk in Denmark, germanwind in Germany, Ålesund Kunskabspark AS in Norway and OrbisEnergy, comprising to organizations Nautilus Associates and NWES Property Services, in the UK) as well as a number of additional and affiliated partners: the Technical University of Denmark and Aalborg University in Denmark, Aalesund University College in Norway, and Catapult Offshore Renewable Energy in the UK, and WAB Windenergie Agentur Bremen-Bremerhaven e.V. in Germany. From the outset the project aimed at including as many as possible of the four cluster organisations' member companies as well as regional and national authorities in the four countries.

3.2. Mapping the Offshore Wind Service sector

The mapping of the Offshore Wind Service sector took place in the project's work package 2: Regional mapping. The mapping aimed at mapping and analysing each of the participating clusters to build up a thorough understanding of each of the clusters´ internal dynamics with particular focus on innovation capacity.

The regional mapping was conducted on the basis of a comprehensive analytical framework developed by germanwind, which guided the way through the mapping process and guaranteed comparable results. The field manual was prepared following the same lines as an earlier Dutch study of the whole offshore wind sector [9,43,44]. As a part of the mapping phase, each of the four cluster organisations carried out a self-assessment of the functions of the technological innovation system in relation to their regional offshore wind service sector. These assessments were purely qualitative and followed the same format as a previous assessment of the North Sea offshore wind TIS.

More detailed descriptions of each of the four clusters were carried out by each cluster organisation and was based on analyses of already existing information, literature reviews, and interviews with experts. In addition, a patent analysis and a bibliometric analysis ware carried out. The result of the patent analysis can be found elsewhere [33]. Based on the cluster descriptions, the partners sketched a SWOT[1] analysis for their own cluster including an analysis of the external strategic environment around each cluster (a STEPLED analysis[2]). Four regional mapping workshops discussed and validated the results. The participants were stakeholders of the clusters representing public administration, industry, and academia. In addition to the facilitators 45 stakeholders participated in the four workshops (Denmark: 16; Germany: 11; Norway: 9; UK: 9). Finally, the partners together carried

[1] Each cluster's internal Strengths and Weaknesses and external Opportunities and Threats.

[2] The external strategic environment was analysed using a standard checklist of factors potentially affecting organisations and clusters: Social, Technological, Economic, Political, Legal, Environmental, Educational and Demographic factors.

out a cross-cluster comparison to identify similarities, differences and complementarities of the characteristics and performance of the clusters.

3.3. Foresighting, strategic orientation and goals

The overall prospective aim of the project was given from its outset; namely, contribution to the offshore wind sectors general targets for cost reduction and develop new and improved OWS business models, technologies and other concepts. As such, the project adopted the industry's ambitious goal of reducing the cost of offshore wind by 40% from today's average LCoE by 2020 [4].

The prospective part of the project took primarily place in work package 3: Regional complementarities and synergies. An important aim was to formulate the overall strategic objectives in OWS; objectives that are important, relevant and possible to achieve for the four clusters involved. The strategic objectives were developed using the Strategic Orientation analysis to examine which strengths and weaknesses will help seize opportunities and defeat threats. Therefore, it directly builds on the SWOT analysis carried out in WP 2. The Strategic Orientation developed at the same workshops as the above-mentioned regional mapping workshops.

3.4. Prioritizing goals and actions

Prioritizing among the suggested strategic goals and possible actions was carried out at a workshop with stakeholders from all four regions. The workshop took place March 10th, 2014 at the EWEA Annual Event in Barcelona. Altogether 31 participants, from the four regions participated in the workshop, comprising representatives from, public authorities, offshore wind industry and organisations for RDI (universities and research centres) and education (higher education, vocational training, and lifelong training).

The key objectives for the workshop were to present the results from ECOWindS Regional Mapping and Strategy Orientation Work Packages, to set clear goals, and to develop actions for the future of the Offshore Wind Service (OWS) industry. Thus, the workshop contributed to prioritizing goals and further developing the action (see the next section). DTU designed a collaborative roadmapping process and facilitated the group through the agenda. The details of the workshop structure and method have been described elsewhere [45].

The workshop started with a presentation about the key findings of the Regional Mapping and proceeded to the Strategic Orientation to set the framework for the actions for the future. Building on the orientation presentations, the group was led to a collaborative roadmapping process. During the roadmapping process, the group discussed key goals for the next 3–8 years in the OWS industry, prioritised them, and continued on to generate ideas for concrete actions to advance towards the goals. Then these ideas for actions were clustered and prioritised. The final stage in the workshop was a session for drafting roadmaps for OWS. The most central goal was agreed to be to lower the LCoE of offshore wind, and the specific target was chosen based on general industry commitment to lowering the cost 40% from 2014 levels by 2020. The target of 40% cost reduction reflected the general discussion in the industry [4].

At the workshop, the participants contributed altogether 97 initial ideas for actions to develop OWS through Research & Development & Innovation (RDI). The initial ideas were clustered to 17 main actions, prioritized by the participants, and organized in a timeline as an initial roadmap for the OWS industry. These actions form the basis of the Joint Action Plan (JAP) that will be described below. These initial ideas were developed further based on the partners' experience and insight, and further sent for a consultation through a survey before finding their final form in the JAP.

3.5. Developing the Joint Action Plan

The aim of the Joint Action Plan (JAP) was to establish a transnational plan of action for supporting the development of the OWS industry through measures of Research, Development and Innovation (RDI). Hence, the JAP is an agenda for collaboration aimed to develop new and improved OWS business models, new technologies, and other initiatives in support of general offshore wind cost reduction targets.

The JAP was a complement to other research agendas on wind power by other organizations. For example, the European Wind Energy Technology Platform (TPWind) has presented a Strategic Research Agenda & Market Deployment Strategy [12] in March 2014, and the European Energy Research Alliance (EERA) Joint Programme on Wind Energy [11] has been running since 2010. These collaboration and the strategies focus on a broad front of technology related to the wind turbines, electric infrastructure, grid integration etc., while the JAP of ECOWindS explicitly and specifically focuses on the services for offshore wind farm installation, operation and maintenance.

The detailed method in this phase comprised five processual elements. First, the development of JAP built on the preceding parts of the project. Second, the groundwork for the JAP was laid in the workshop as described in the previous section. The process after the workshop has concentrated on following up on and refining the stakeholders‘ ideas and synchronising them with other ECOWindS findings. This work contributed to the JAP and the Guidelines for Implementation [46], which are available from the ECOWindS project website [47]. At the time of the writing, the ECOWindS consortium is conducting further stakeholder consultations on the actions, which contributed towards the final Joint Action plan, published late autumn 2015.

Third, the ECOWindS partners elaborated the actions side-by-side with the further development of the Strategic Orientation (WP3) and later Supply and Demand of Research Development and Innovation (WP6). Each of the actions were described using a template with information on 1) action title, 2) timing, 3) type (RDI = problem driven Research Development and Innovation; IND= Business and industry development actions, including common infrastructure; POL= RDI and industrial policy actions, improvement to framework conditions), 4) implementation level (International/European/National/Regional), 5) stakeholders, 6) rationale for the action, 7) goal of the action, 8) activities including milestones, 9) deliverables, 10) anticipated impact, and 11) resources (time, funding and funders/investors). For communication purposes each action were condensed into a bit more than one page.

Fourth, the elaborated actions were discussed and developed in a working meeting with the partners in September, in Copenhagen. The JAP actions were discussed and developed in a working meeting with the partners in September 2014, in Copenhagen. The meeting brought the partners' joint expertise together and synchronised between the parallel work packages.

Fifth, the elaborated actions were exposed in a stakeholder consultation that followed as an on-line survey to key stakeholders. The consultation was executed between April and June 2015, with altogether 81 stakeholders participating. The stakeholders were mostly representatives from the industry, and research and education institutions, with some answers representing the third helix. The responses were incorporated in an updated and final Joint Action Plan.

As a part of the JAP, the project comprised a comprehensive dissemination plan targeting in particular four groupings: 1) Enterprises in the OWS industry including both enterprises that presently work directly in OWS value chains at the moment and enterprises with relevant capabilities to contribute to OWS value chain and relevant RDI; 2) Relevant researchers in relevant disciplines such as naval architecture, supply chain management and logistics, operations research/management; 3) Policy makers and civil servants include those who oversee energy policy, RDI policy and environmental policy, as well as occupational health and

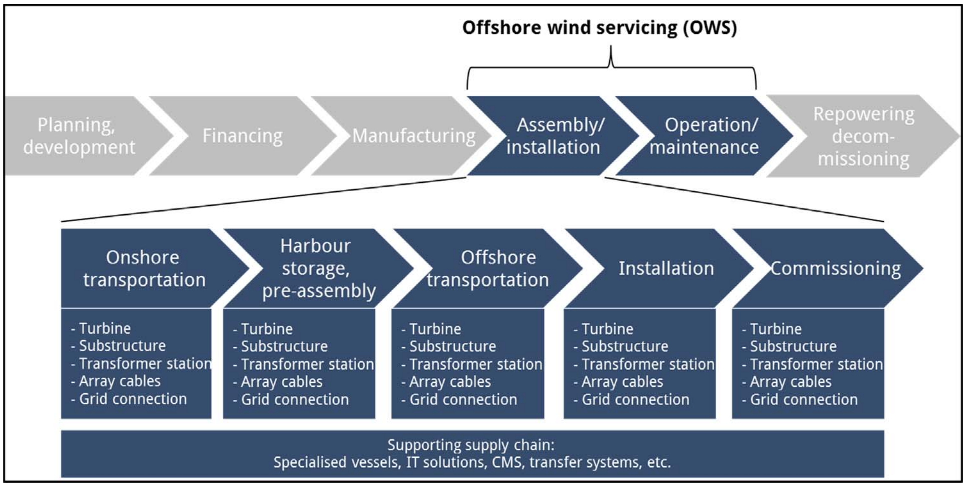


Fig. 2. Detailed breakdown of Assembly and Installation. Source: germanwind GmbH [48]

safety, and the civil servants who design and implement legislation, regulation and policy instruments that are relevant for the OWS industry; and 4) Opinion formers such as journalists in the popular media, political and business leaders, and Non-Governmental Organizations (NGOs).

The project utilised a wide range of communication channels and media including: 1) Trade and professional magazines for offshore wind and associated industries, 2) Daily newspapers and magazines, 3) Academic peer reviewed journals, 4) Trade shows and professional, 5) Academic, and 6) Social media and networking platforms.

In addition to the JAP, which is a high-level strategy, the project included further work on developing training, and concrete ideas for RDI projects and other activities under work packages 5 and 6 to support the JAP and enhance the impact of the project. In practice, there were two major outcomes. First, a simulator platform and usage guidelines were developed. Second, the partners developed a list of project ideas together with regional stakeholders for implementing the actions. These ideas were evaluated and rated against the project objectives and disseminated through the partners.

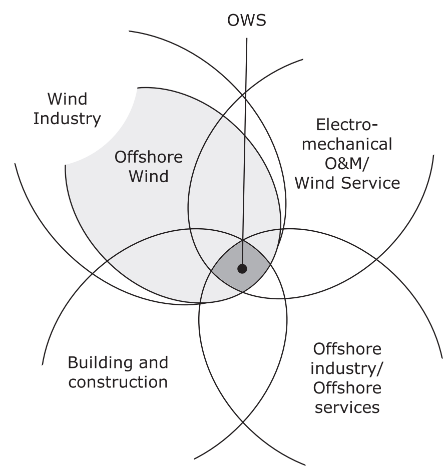
4. The North Sea Offshore Wind Service industry

This section is based on data collected during the regional mapping (work package 2) This article focuses on four relevant issues: 1) the market sizes today and in the future, 2) companies in the four clusters 3) organisational issues of the four cluster organisations, 4) collaboration patterns, and 5) comparisons with earlier studies.

4.1. Definition of the Offshore Wind Servicing Sector

The OWS industry is still in its infancy, or emergent phase, in most countries. The development of the industry is driven by the push for more renewable energy generation capacity in general. Due to the ever-increasing offshore wind capacity, OWS is growing in significance and volume. While the OWS as an industry is developing, its roots can be found in the following established industrial sectors:

- Offshore industry; offshore marine service industry and offshore support vessels, including crane vessels, anchor handling, towing and supply vessels, jack-up barges and platform/multi-purpose support vessels
- Electro-mechanical installations, operations & maintenance service industry
- Civil engineering, marine construction, cable laying.



OWS lies at the intersection of wind energy, wind-relevant O & M, building and offshore service industries. The term ‘offshore industry’ in common usage refers to the offshore oil & gas industry, which clearly has aspects that are adjacent and analogous to OWS, but may in the short term actually compete with offshore wind for OWS resources. Across the sector has seven core technological competence areas related to the:

- Turbines
- Support structures
- Inner-park cabling
- Transformer stations
- Grid connections
- Vessels
- Logistics (onshore and offshore).

From the perspective of value chain, OWS comprises the activities from component assembly to operation and maintenance stages of wind farm activity. OWS could also be extended to end-of-life activities such as re-powering and decommissioning, however they are excluded from this study. This is summarised in Fig. 1 and Fig. 2.

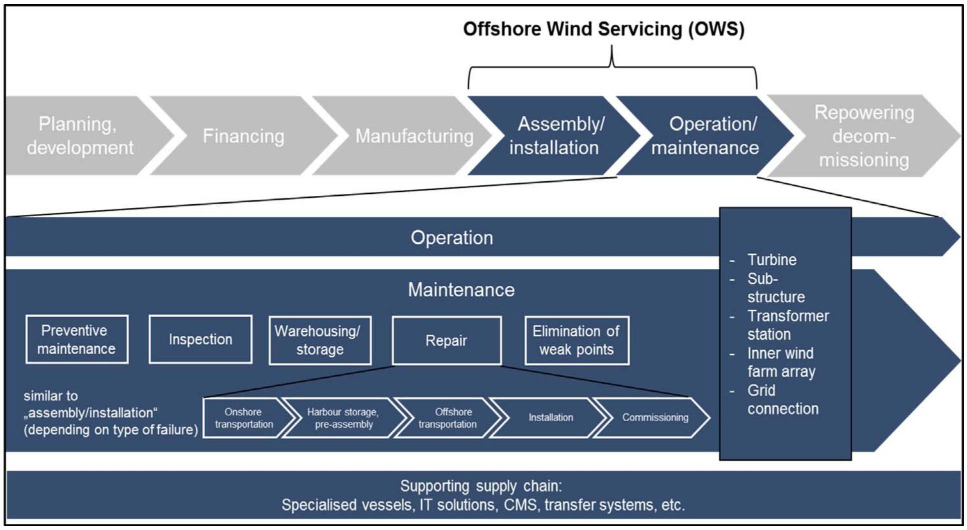


Fig. 3. Detailed breakdown of Operations and Maintenance. Source: germanwind GmbH [48]

4.2. Overview of the market

Several studies have estimated the market size of the North Sea and global offshore wind sector. An American report has summarized these studies and compiled a status as of June 30, 2015 [49]. According to that report, 8990 MW of offshore wind power was installed and 4452 MW was under construction by mid-2015. Furthermore, the report concludes that 40,000 MW either are under contract or approved and that the global offshore wind industry appears to be signalling growth. (Figs. 3–5)

The three countries UK, Germany and Denmark have the largest installed capacity in a global comparison. See Table 1. If the Netherlands (247 MW) and Norway are added the North Sea installations of offshore wind constitutes 85% of the global installations, and 59% of the global installations under construction. Hence, the North Sea is clearly a global leader in offshore wind power.

Whereas several studies have estimated the market size of the North Sea and global offshore wind sector no comprehensive overviews exist of the present and future market value specifically for the offshore wind service (OWS) sector. Only few publicly available analyses exist on the cost of operations and maintenance of offshore wind turbines. An example of the latter is a study by the Crown Estate in Britain [4]. Because of this lack of accessible evaluations, the future value of the market for offshore wind services was assessed as a part of the EcoWindS project during the 2014. A total of 25 publically available reports, presentations and fact sheets were reviewed and data from nine of these was included in the analysis. The assessment was based on a number of assumptions, and it was chosen to try to concentrate on an offshore wind farm with the following approximate characteristics, which mark what might be called a current generation offshore wind farm:

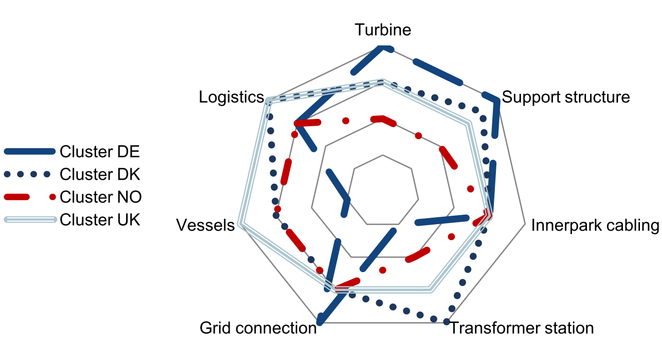


Fig. 4. Assessment of competences in the core technology areas in the clusters by the ECOWindS actors. [48].

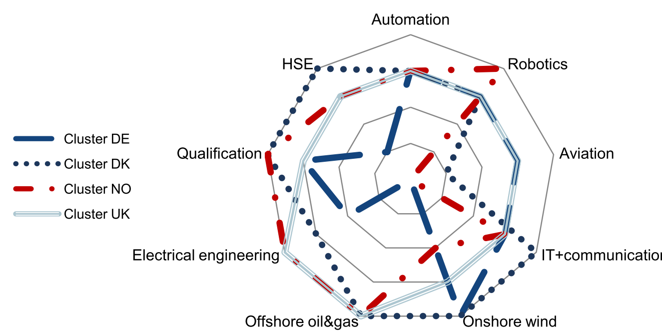


Fig. 5. Assessment of competences in related industries in the clusters by the ECOWindS actors. [48].

Table 1
Offshore wind power installed and under construction in MW by June 30, 2015 [49].

	Germany	Denmark	Norway	UK
Installed	1505	1271	2	4625
Under construction	2108	0	0	503

- Wind farm capacity: 300–500 MW
- Wind turbine rated power: 4 MW
- Distance to shore/port: 40 km
- Depth of water: 30–40 m
- Grid connection: High Voltage Alternating Current (HVAC)
- Net annual energy production: 3700 MWh/year/name-plate MW

As further assumption, the grid connection is considered as being developed for, and included in the capital costs of, the wind farm project (i.e. not developed for a collection of wind farms and not provided by a TSO). The annual power transmission charge, (a type of annual fee for the use of a grid connection that is constructed and operated by a separate entity, as in the UK) is not included in the annual O & M costs. Furthermore, the analysis adopted the figure of new capacity of offshore wind in the period 2015–2020 of 19 GW as assessed by two recent reports [50,51].

Based on these assumptions, annual market for services related to installations in the period 2015 – 2020 amounts to approximately 1.9 billion Euro, and annual spending on service related to operations and maintenance amounts to around 1.3 billion Euro. However, it is important to note that these figures do not include anticipated cost reductions in the period. (Table 2)

Table 2
Estimated OWS market size 2015–2020.

Estimated total market size		
New capacity to be installed 2015–2010	19	GW
Total capital spent on offshore projects 2015–2020	69000	M€
Total capital spent on *installation phases* 2015–2020	14000	M€
Total annual spent on *O & M* in 2020	1995	M€/yr
Estimated market size for independent contractors (non-OEM, utility, or TSO)		
Potential spent on service providers, *installation* 2015–2020	1900	M€/yr
Potential spent on service providers, *O & M* in 2020	1300	M€/yr

Table 3
Overview of installation costs for offshore farms.

Included in category	Onshore transportation	Harbour storage, pre-assembly	Offshore transportation	Installation	Commissioning	k€/MW
Turbine						430
Support structure						120
Array cables						160
Transformer station and grid connection						30
Estimated share	5%	15%	15%	60%	5%	

Going deeper into the figures, the bulk of capital expenditure is expectedly on the hardware; out of a total 3630 k€/MW, 67% is the tangible infrastructure. For the rest the OWS operations account for 20%, and project development and management account for the final 13%. In terms of distribution along the OWS value chain, the following table presents an estimate of the breakdown along the phases. During the overall installation and commissioning phase, the actual installation or erection counts for 60% of the whole installation cost, but pre-assembly and water side handling as well as offshore logistics count for as much as 30%. (Table 3)

The cost of installation is measured in € per MW of nameplate capacity and it is stable for a given class of turbines. However, going forward the size of turbines is expected to grow, currently the large manufacturers are either developing or have launched 6–8 MW class turbines. Introduction of these can be foreseen to raise CAPEX in terms of more expensive turbines and substructures, but also lower the OPEX as smaller number of turbines and consequently less operations are required for a given farm capacity.

After commissioning, the OPEX is estimated at 120 k€/MW/year of operation. The surprising finding is that to date the split between planned maintenance and unscheduled repairs is almost 1:2, the exact percentages are 20% of maintenance and 54% repairs. To corroborate this, during the project reports of unscheduled drive train, converter and transformed replacements, and especially inner-park and offshore cabling repairs were routine. This finding suggests that there are significant cost savings and lowering effect to LCoE to be reaped when the technology and O & M protocols mature and reliability is raised, which will both lower gross cost and raise capacity factor.

To further evaluate the reliability and validity of the estimates, in the absence of directly comparable market size or cost estimates, the projected installed capacity, specific costs, and total committed capital estimates, as well as LCoE were calculated and compared to existing estimates. It was found that the estimates are within a reasonable margin of error accounting for difference in assumptions.[3]

Table 4
Number of companies involved in the Offshore Wind Value Chain in each country. *) No national data are available for UK and the included numbers are only for the OWS cluster of East Anglia. [48].

	Germany	Denmark	Norway	UK*
Assembly/Installation	269	229	13	22
Operation/Maintenance	419	220	9	39

4.3. Organisations in the Offshore Wind Service sector

The ECOWindS project was a collaboration between cluster organisations within offshore wind servicing in four regions around the North Sea. The partner regions were:

- South Denmark (Region South Denmark),
- East of England (East Anglia, Counties of Cambridge, Suffolk and Norfolk),
- North West Germany (Bremen-Bremerhaven region, federal states of Bremen, Hamburg, and Niedersachsen, and as an extended region Schleswig-Holstein, Mecklenburg-Vorpommern and Nordrhein-Westfalen as well) and
- Møre in West Norway.

Due geographical size and due to data quality, the whole of Denmark and Norway were each considered as one unit in the analyses.

The following table is an estimate of OWS companies per region. However, the figures contain some uncertainties as some enterprises may have the relevant and necessary capabilities, but they might not see themselves as OWS enterprises and vice versa. Long and complex supply chains and rapid changes in the sector introduce another uncertainty. Thus, the cluster organisations have estimated the number of companies based on their membership databases and their mapping relevant regional and national companies in the sector. See Table 4.

In a similar way, also the number of knowledge institutions in the Offshore Wind sector was assessed. See Table 5. These numbers can be compared with the findings based in a Dutch study of the European offshore wind innovation system [9]. The study presents that in the four countries around the North Seas there are 194 knowledge institutions in Germany, 66 in Denmark, 170 in the UK and 43 in the Netherlands. An important reason for the differences can be that the Dutch study includes all institutions disregarding size or importance. For example in Denmark, the three major institutions account for 57% of all publications. The numbers in Table 5 only included organisations assessed to be significant in size or importance. Taken this into account the numbers in Table 5 gives a more realistic picture

[3] The one aspect that is clear from the search for data on costs for project development, installation and O & M is that there is a significant range in the figures available. Reasons for this include: 1) Offshore wind farm projects are very individual and costs are sensitive to water depth, distance to shore and experience of the developer. 2) It is difficult to be certain that figures quoted for similar activities actually contain the same items. 3) Currency exchange rates play a large role in project finances and the conversion of total spends for comparison in the same currency. As much offshore activity takes place in the

(footnote continued)
UK the GBP to € exchange rate is most important. Between 2010 and 2014, the rate has had a maximum of 0.9 to a minimum of 0.72, a fluctuation of some 20%. 4) Amounts quoted are not always clear on what year the value is based on.

Table 5
Estimate of the number of knowledge institutions involved in offshore wind and number of staff within these institutions allocated offshore wind service.[48].

	Germany	Denmark	Norway	UK
Number institutions	24	13	3	7
Estimated staff	> 600	350	360	> 600

than the numbers in the Dutch study.

4.4. Core competences and complementary competences

As discussed, the there are seven key technological competence areas related to OWS.

- Turbines
- Support structures
- Inner-park cabling
- Transformer stations
- Grid connections
- Vessels
- Logistics (onshore and offshore)

The competences in the regions were mapped from different perspectives. The regional actors did a qualitative mapping. Side by side with the qualitative mapping, a patent analysis was conducted, details of which are reported elsewhere [33]. The regional actors' perception is that they cover the value chain more or less equally, however when going deeper into the competences, there are more nuances that are affected by the historical path of the regions. The core area of turbine technology are the strongest in Denmark and Germany, in line with the In fact over 80% of world's installed offshore capacity have been delivered by Vestas Wind Systems and German-owned Siemens Wind Power located in Denmark [3].

A combination of a drive for energy security and environmentalism has driven wind energy in Denmark and Germany before many other EU member states. The long history of utility scale (onshore) wind power generation and the relative importance in energy mix may explain the advanced manufacturing capabilities and position in the value chain. However, as professed by the capacity figures discussed above, almost half of the installed offshore wind capacity in the whole world reside in the UK. The government of UK has engaged in quite purposeful niche creation to accelerate renewable energy adoption and wind energy has been benefitting in particular [9,52,53]. This also explains why the UK is rated as strong in the O & M part of the value chain, while it lacks capabilities and capacity in manufacturing components. Norway in turn has very little installed capacity at the time of writing, but Norway has a history in servicing Offshore Oil & Gas operations, which contributes to the capabilities for OWS operations.

The assessment suggests that each region has a distinct profile of competences and related industries that contribute to OWS in various ways. Similar conclusions have been presented based on analysis of patenting in the same regions, where it was found that especially Germany, Denmark and Norway has very sharp concentrations on specific technology areas. In Denmark that was turbines, in Germany positioning & anchoring and grid connections, and in Norway vessels. In the UK the profile is more even across the relevant technologies [33].

Within the clusters, the actors rated collaboration between actors rather low on average. For example direct B2B collaboration or collaboration with universities and especially research institutes was rather low. The most prevalent type of collaboration was between individual enterprises and 'innovation service providers' such as (engineering) consultancies, business parks, business developers, and different business intermediaries.

4.5. The functions of the Offshore Wind service innovation systems

As a part of the mapping phase (see Section 3.2) each of the four cluster organisations carried out a self-assessment of technological innovation system in relation to offshore wind service sector. This assessement followed the same format as a previous Dutch study of the North Sea offshore wind TIS including the seven functions of such analyses [9]. The functions are: 1) Experiments by entrepreneurs, 2) Knowledge development, 3) Knowledge exchange, 4) Guidance for search, 5) Market formation, 6) Resource mobilisation, and 7) Creation of legitimacy. The scoring from 1 (very weak) to 5 (very strong) was carried out qualitatively by the participants in workshops on each national cluster. See Fig. 6. The two studies use slightly different terminology. The Dutch study of offshore wind uses the term 'Knowledge diffusion' and the EcoWindS projects uses the term 'Knowledge exchange'. The Dutch study of offshore wind uses the term 'Guideance of the search' and the EcoWindS projects uses the term 'Commitment & Support'. Ideally, the score on each function should be calibrated according to the development stage of the technological innovation system. Wilson has analysed different development stages of energy technologies, including wind power, and the implications for policies at each stage [54]. However, our data does not take into account the development stage but must be seen as a 'snap shot' of the situation in the period of the assessment.

It looks as though the OWS and OW innovation systems are strong overall. Still, there are some challenges going forward. These come from two directions, one is technical challenges and the other is business. On the technical side, challenges tend to revolve around lack of technical standards relating to key interfaces of components both in the installation phase and during operation. These interfaces include non-standard technical interfaces between the major componentry, but also non-standard tower access solutions, boat landings, and helipads to name concrete examples. The business challenges include lack of communication both horizontally and vertically in the value network between suppliers, original equipment manufacturers (OEMs), service providers, contractors, developers and operators. Complexity of value chain and poor communication in turn have their own effect to resource congestions and bottle necks in delivery, both in terms of availability of adequately specified equipment, ports and vessels as well as skilled and qualified labor. Additionally, overlapping and sometimes conflicting Health, Safety and Environmental regulation, as well as planning and permitting process pose challenges for O & M and installation. (c.f. Stolpe et al., 2014)

The OW industry is very focused on lowering the total energy cost in terms of LCoE towards market price of electricity. This effort hinges on innovation, but also optimization and standardization. For example in EWEA Offshore 2013 and EWEA Annual Event 2014, which are some of the world's largest wind power industry events and conferences organized by European Wind Energy Association, the talk words were *standardization* of wind farm and particularly of offshore wind components and interfaces, and *industrialization* as in moving to mass production of components to reap economies of scale.

These factors have bearing on the innovation system as industry resources are committed to incremental improvements. It is not to say that innovation is halted, but focused on incremental improvements of processes, services, and existing dominant designs.

5. A Joint Action Plan

The Joint Action Plan (JAP) described in this section is the product of the foresight process described in the first sections of this article. Details of the process, such as the method for collecting stakeholder feedback are detailed in [45,46]. This section will focus on describing the foresight findings as it were.

The main substance of the JAP consists of eight 'Actions', that can be viewed as individual projects and programs within a portfolio. These

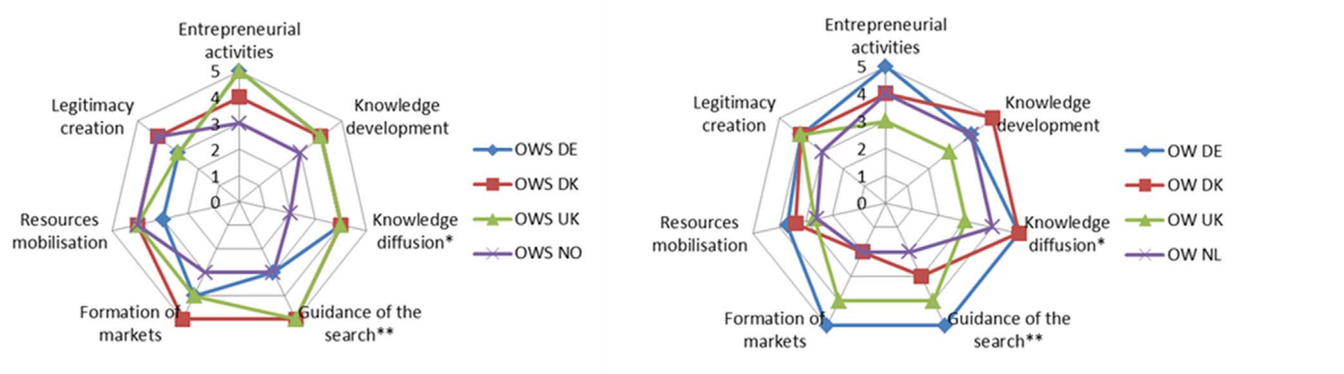


Fig. 6. Comparison of the functions of the Technology Innovation Systems for Offshore Wind Service (OWS, left) sector and Offshore Wind (OW, right) sector in different countries. (Authors' own creation, Data for the latter stems from an earlier Dutch study [9].).

Table 6
Overview of the actions (Authors' own creation, adapted from [46]).

No.	Action	Goal	Rationale
1	Establish communication and coordination of RDI between regions	To build a platform that bridges between national collaboration initiatives to support international RDI and business development.	Building collaboration in the early stages of the development of the OWS industry helps reduce fragmentation and increases opportunities to leverage complementary assets for innovation.
2	Establish a value proposition for OWS	To establish a clear value proposition for OWS as an industry and the enterprises with the ecosystem of offshore wind.	The value chain of OWS is fragmented over different industries. A clear value proposition enables developing a clear message for the OWS industry when dealing with stakeholders.
3	Establish an RDI program specifically for OWS	To develop an industry-wide research and development agenda specifically for OWS.	Specific OWS technologies and solutions are not recognized in exiting offshore wind agendas. There is agreed to develop a roadmap specifically for OWS to capture the cost reduction opportunities.
4	Contribute to international, OWS specific, standards	To develop OWS specific technical standards.	Lack of (technical) standards for components and interfaces on all levels, and the resulting complexity of offshore farm planning, installation and operation are recognized challenges for offshore wind in general and OWS specifically.
5	Establish a skill profile and OWS specific training programs	To develop OWS specific and EU-wide training programs and certificates based on a common profile that enable working on OWS and installation sites across jurisdictions.	Current education and training does not provide people with the right skills, qualifications and certificates to work on the major offshore sites, which in turn lowers labour mobility, and efficiency and availability of OWS.
6	Establish a database and portal for OWS data	To develop a database interface and information front-end that enables sharing of relevant information and data between stakeholders.	Lack of current information and data related to OWS operations inhibits diffusion of best practices and is a bottleneck for innovation.
7	Establish RDI infrastructure for OWS	To develop test sites for OWS technologies in conjunction with existing farms or test sites.	Existing test sites are almost exclusively for turbine and grid technologies. Development of OWS and related technology such as installation and maintenance concepts need proving grounds as well.
8	Contribute to harmonization of Occupational Health & Safety regulation	To contribute to harmonisation of Occupational Health and Safety regulation between European regions.	Requirements for formal qualifications, Occupation Health and Safety and training certificates vary arbitrarily between jurisdictions. Harmonizing the regulatory framework without endangering workers enables better availability of OWS and leads to cost savings.

actions are classified into four work streams that address the main goals for the industry. The underlying principle of the actions and structure of the JAP is to build a collaboration platform for the partners and their regions to increase networking and bring together complementary assets and capabilities that enable further innovation. The goals state is that increasing collaboration from the present increases innovation and continuous improvement, which in turn brings the industry closer to developing standardization and interoperability, and ultimately economies of scale. (Table 6)

Following this logical framework, the *first work stream* of proposed actions include three coordination actions that build the necessary networks and social capital that is needed to achieve the major actions. The first action (Action 1) is setting up a knowledge sharing initiative between the clusters. Lack of communication and coordination is a recognised challenge within the offshore wind value chain. The initiative was driven by the industry associations, first by the ECOWindS partners and later a Post-ECOWindS consortium comprising major European Offshore Wind and OWS industry associations and cluster management organisations. Setting up concrete networking activities locally and building international linkages enables networking within the industry, which contributes to building future RDI and business ventures. The second proposed action (Action 2) to be undertaken concurrently with the first is outlining a clear value proposition and message for the OWS industry within the ecosystem of offshore wind.

The third action (Action 3) is setting up a mission-oriented and OWS-specific RDI program. The added value of the program is to complement the existing programs and roadmaps reviewed above by consolidating OWS specific topics to one program, to complement existing research, development & innovation agendas from EERA, TPWind or MegaVind [55–57]. The key in this action is to leverage the knowledge-sharing platform to build serious consortia around the topics identified during ECOWindS and continue to building projects and proposals around the stakeholders' interests. The action was driven by a post-ECOWindS consortium with stakeholders.

Additional fourth coordination action is building an OWS database and portal (Action 6) for a platform for communication and RDI. The aim of the database is to provide a one-stop shop for information that enables benchmarking reliability and service efficiency and optimizing services across farms relevant specifically for OWS stakeholders. The key in Action 6 is not to duplicate the effort already in progress in the UK (SPARTA, System performance, Availability and Reliability Trend Analysis project coordinated by the ORE Catapult with collaboration from The Crown Estate) and Germany (Offshore-WMEP, Wissenschaftliches Mess- und Evaluierungsprogramm [Scientific Measurement and Evaluation Program] coordinated by Fraunhofer Institute for Wind Energy and Energy Systems Technology IWES), but to build on the existing efforts.

Building on the foundation of coordination the *second work stream* is 'Research, Development and Innovation (RDI)'. The core of this stream is a research program of OWS specific research program (Action 3). The key underlying theme in OWS specific RDI is development of interfaces between the components of a wind farm and the service equipment. The aim is to achieve a degree of standardisation that enables effective installation and O & M of offshore farms, while not being stifling to innovation in key technical areas that add value to power generation.

The work in this stream build directly on the RDI program set with the stakeholders as the action (Action 3) unfolds. The program is highly synergistic with the harmonisation actions (Actions 4, 5, and 8 below) as joining forces in RDI open the door to develop effective industry standards that pave the way for official standardization. The stakeholders have raised certain key themes for RDI. From a technical OWS perspective, the installation cost within the given conditions depends on the ease of installation of the components, their compatibility with each other, and the installation equipment. Similarly, the effectiveness of the O & M services depends on interoperability and compatibility between service equipment and vessels with wind farm components. The OWS specific aspect is development of robust procedures for installation, operation and maintenance, to increase availability of service, effectiveness and independence from the weather conditions.

A related core action in the mid-term is establishing OWS specific test sites and other research infrastructures (Action 7). Present test sites are very focused on improving reliability and performance of turbines alone or as farms. However, the existing sites do not enable testing core OWS technologies and procedures that are related to installation and O & M operations and secondarily on foundations, grids, transformers and turbines insofar that these major components impose demands on the OWS procedures.

The *third work stream* is 'harmonization and standardization'. The core action is drive for OWS specific technical standards (Action 4) together with key OEMs. There are serious on-going efforts for standardization, not the least the IEC TC88 on wind turbines and components [58]. The objective of this action is to complement, provide added drive and introduce OWS specific topics and viewpoints to existing standards committees and processes, and secondarily set up new standards initiatives within existing frameworks as needed.

The harmonisation work stream intersects with skills (see Action 5 below) in the proposed long-term action to contribute to harmonisation of formal and informal qualifications and training certificates needed to work on OWS across the ECOWindS regions and beyond (Action 8). The aim is to propose harmonisation between national occupational health and safety (OH & S) guidelines, to find an acceptable level of protection and harmonised certificates for OWS. The work is parallel to Global Wind Organization (GWO) OH & S work and compliments it for offshore specifically. An additional topic is harmonising health, safety, environmental and quality (HSEQ) policies together with the training certificates to enable efficient resource use.

The *fourth work stream* is 'skills and qualifications' that relates strongly to harmonisation action on skills and training (Action 8). The aim of the sill work stream is to ensure that there is a skilled and qualified workforce to ensure efficient operation of offshore farms and by extension reliable delivery of power. Offshore wind capacity is projected to grow tremendously, which means that OWS capacity has to grow proportionally. However, the existing OWS resources are already employed close to capacity.

The main action proposal is to develop OWS specific training programs that ensure enough skilled labour is available for OWS in the future (Action 5). The aim of the action on one hand is to identify the core skill sets and formal qualifications needed to work effectively and safely in various OWS tasks, and design a portfolio of training programs to deliver the necessary skills and qualifications both within secondary education and as life-long learning. On the other, the aim is to establish a 'skills gap' for the need of training and education in quantitative terms to enable OWS industry and educators to see what concrete action is needed.

The proposed sequence of actions is built towards the goals set for the OWS industry. The actions are laid out in work streams, each corresponding to the goals. For the sake of clarity, the interdependencies are not laid out in the figure. The communication is the foundation for gathering political and material support, and building collaboration networks for implementing the actions. Research, development and innovation interfaces with communication and makes use of the networks. The standardisation and skills activities in turn make use of research and development activities.

Concerning the implementation of the actions ad JAP as a whole, the 'owner' of the JAP is in a sense the OWS industry, who has an interest to drive the JAP forwards. It is proposed that a post-ECOWindS consortium that comprises industry associations, OWS enterprises and operators who together have the most direct interest in the matter is to be formed to continue driving the JAP actions and keeping the plan up to date.

In terms of the individual actions, it is proposed that a specialised consortium of stakeholders implements each action with the most interest to drive the action forward. There are two benefits. First, it ensures that the best capabilities and relevant interests are represented in implementation of each action. Second, the responsibility is distributed outside the (post-) ECOWindS consortium to enable more effective parallel implementation of the actions.

As for the level of implementation, the actions are primarily to be implemented on the cross regional or international (European) level following the logic of the JAP. Despite that, some of them have repercussion on regional and organisational level. To take an example, the RDI programme (A3) includes sub-actions that can be completed by one organisation if so desired. In addition, the skills action (A5) can be partially implemented by individual organisations who wish to offer training and education for OWS. However, these two also include trans-national components that aim to bridge the strengths of various actors to create international impact. (Fig. 7)

6. Discussion and conclusions

This article sets out to review the Offshore Wind *Service* innovation system for the purposes of foresight following the framework for Innovations Systems foresight.

The work started with a comprehensive mapping of the resources in the four regions, assessment of the innovation systems, and proposing a roadmap for development. As such the process fulfils the definition of a innovation system foresight approach as proposed by Andersen and Andersen (2014).

One overarching theme in the actions and joint action plan altogether is to find a common ground between stakeholders across national borders. The rationale is to bring together the best capabilities across regions and avoid reinventing the wheel. International cooperation enables capturing a larger 'home market' and broader base of funding as well. The following key points summarize some of the specific of the JAP implementation:

Leverage a common vision to develop cooperation – Developing a

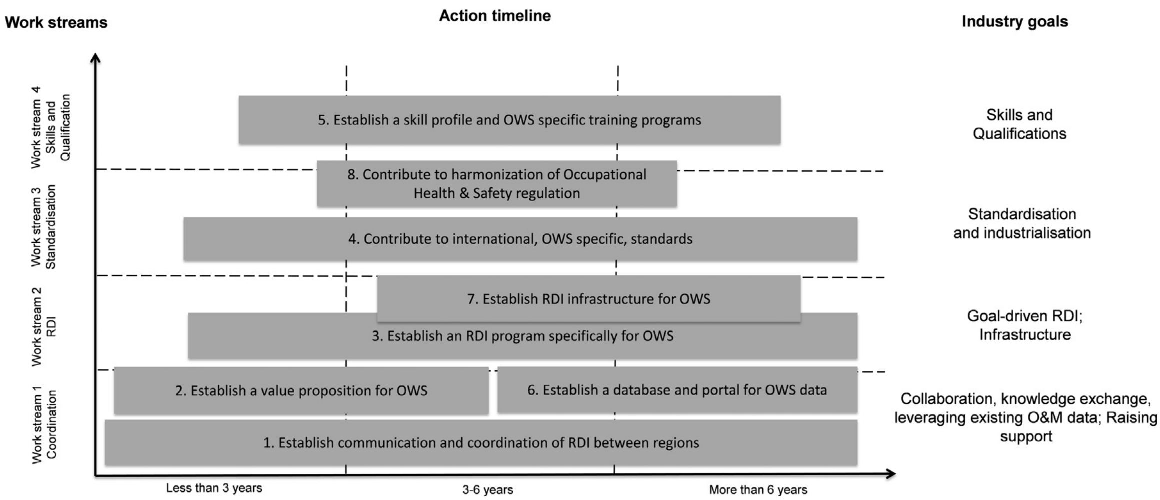


Fig. 7. Joint Action Plan timeline with work streams. (Authors' own creation based on [46]).

common understanding about the direction of search enables cumulative RDI between stakeholders, which together with scaling the production of hardware up, lead to more standardization and interoperability between various components, in turn enabling more efficient installation and O & M.

Use the location and existing networks to develop RDI further – build on the advantages of proximity and existing networks to develop further collaboration to bring complementary assets and capabilities together.

Invest in following the actions through – the plan laid out here proposes a reasoned course of action for the OWS industry. Building on those foundations requires ownership of the agenda and individual actions among organizations that have a role in building networks in this industry. The original project was laid out between regional industry associations who will continue to support implementation.

Based on their analysis the earlier mentioned Dutch study recommended that the aspects of the innovation system that particularly need addressing are resource mobilization, market creation and legitimisation [9]. They note the same misalignment in regulatory frameworks, shortages in skilled labour, as well as the overall challenge of energy cost and reliability and technical issues with grip and integration of wind power. As discussed above, our assessment is similar, and the JAP actions address two of these challenges. Legitimation is supported in purporting to create a clear message for OWS and development of networks, and indirectly by working towards lowering the LCoE. Resource mobilization is supported by the actions on training and education as well as harmonization of regulation and certificates. Although, it is an important aspect for the long-term survivability of the whole offshore wind industry, market creation is outside the scope of the JAP. However, it can be argued the JAP contributes to that indirectly, being geared towards cost reduction as an overarching objective for the whole agenda.

Foresight exercises are often criticized for not taking sufficient notice of the demand for knowledge, existing competences, and reality and wishes of firms, policy makers and other key stakeholders [27,59]. The Innovation System Foresight approach emphasises to include viewpoints from key stakeholders in the process. Hence, this project included four industry associations and two research institutions as core partners, and in addition two industry associations and one research institution from the same regions were included as associated partners. As a result, the project and its results were well integrated with the interest of the users, and the project has spun out new collaborations between the former ECOWindS partners, as well as new projects based on the suggestions given in the project conclusions. As an example, a representative of The Crown Estate told in the final conference that they were looking to implement relevant suggestions from the JAP in further work. This clearly supports literature's suggestions that seriously inclusion of key stakeholders increases the impact of such processes [42].

Key priority for this project was to support the industry, whereas gaining knowledge was a secondary priority. Thus, the stress was on useful information and not on validation of information. This orientation is also evident on the liberal use of qualitative data and self-assessment in the analysis. the partners felt it uncomfortable to base conclusions on patent analyses or bibliometric analyses, as they viewed these as surrogate measures too far removed for what they considered the reality of the industry and its key stakeholders. While qualitative data are valid as such, the risk in terms of using exclusively qualitative data is that especially when dealing with interviews, the interviewer is interpreting others' interpretations of the present and the future [37]. However, the findings in this study are corroborated by other studies in the area, and the validity of findings are in general reasonable. As such, the mapping is less rigorous as the gold standard of innovation studies, but still useful and usable platform for foresight. Still, the authors of this article recommend to include both qualitative and quantitative data in similar innovation system foresight processes and to allocate more effort in explaining stakeholders the particular strengths and weaknesses of each type of data.

While discussing rigour, it might be asked that is not the purpose of foresight and strategizing in the broader sense to be useful for decision-making. In relation to this, for example Foray and his colleagues have discussed this theme in the context of smart specialization, which is highly relevant [20]. Their assessment was that smart specialization policies and strategies, at least initially, were often made more from wishes and hopes, than empirical facts. This illustrates that while research is not only judged by its rigor, in this sort of applied research, disregarding facts concerning the framework conditions, capabilities and other empirical facts will not lead to the intended result. Furthermore, Foray et al. discuss that smart specialization or any other industrial policy may turn against itself if it creates rent-generating organizations that cannot survive without public assistance. Fact-based analyses and policies can assist in avoiding such instances, as successful regional specialization is not based on implementing the same policies as other competing regions. Rather, successful regional specialization is based on identifying the idiosyncratic combinations of capabilities and supporting the development of the innovation system around the region.

These reflections also point out questions for further research. The paradox in these types of projects is that the process needs to be transparent and inclusive for the policy makers and the key stakeholders to understand and trust the results to get maximum impact. However, occasionally this might pose challenges for designing a rigorous (foresight) process. The overall question is how to design innovation systems foresight and related analyses to be inclusive for maximum impact, yet isolate the direct and at times conflicting interests of the stakeholders from rigor and impartiality. Another question is that how can innovation system foresight be conducted efficiently and effectively. To use ECOWindS as an example, the project runtime was three years (November 2013 to October 2015), and as some of the stakeholders pointed out, once the project kicked off, it was hot on stakeholders agenda, so in their interest was to have usable results within some month or within a year while they were still receptive, not in three years.

Acknowledgements

The work behind this article has primarily been performed within the project European Clusters for Offshore Wind Servicing (ECOWindS) funded by the European Union's Regions programme. The academic part of the article was furthermore developed within the project Strategic Research Alliance for Energy Innovation Systems and their Dynamics (EIS) funded by the Danish Council for Strategic Research. The authors would like to thank partners from both projects for their contributions; in particular to Anne Wieczorek, Technical University of Eindhoven, and Marko Hekkert, Utrecht University, for comments on drafts for this article.

References

[1] European Commission. A European Strategic Energy Technology Plan (SET-Plan) - Towards a low carbon future. European Union; 2007.
[2] IRENA Secretariat. Wind Power. Abu Dhabi, UAE; 2012.
[3] European Wind Energy Agency. The European offshore wind industry - key trends and statistics 2013. Brussels: 2014.
[4] Arwas P, Charlesworth D, Clark D, Clay R, Craft G, Donaldson I. et al. Offshore Wind Cost Reduction. Pathways Study. London, Edinburgh; 2012.
[5] Stolpe M, Buhl T, Sumer BM, Kiil S, Holbøll J, Piirainen KA. Offshore wind energy development. In: Larsen HH, Petersen LS, editors. Wind energy — drivers barriers High. shares Wind Glob. power Gener. Mix. Kongens Lyngby, DK: DTU National Laboratory for Sustainable Energy; 2014. p. 43–51.
[6] Green R, Vasilakos N. The economics of offshore wind. Energy Policy 2011;39:496–502. http://dx.doi.org/10.1016/j.enpol.2010.10.011.
[7] Azau S, Casey Z, editors. Wind in our Sails: The coming of Europe's offshore wind energy industry. Brussels, BE: European Wind Energy Association; 2011.
[8] Rodrigues S, Restrepo C, Kontos E, Teixeira Pinto R, Bauer P. Trends of offshore wind projects. Renew Sustain Energy Rev 2015;49:1114–35. http://dx.doi.org/10.1016/j.rser.2015.04.092.
[9] Wieczorek AJ, Negro SO, Harmsen R, Heimeriks GJ, Luo L, Hekkert MP. A review of the European offshore wind innovation system. Renew Sustain Energy Rev 2013;26:294–306. http://dx.doi.org/10.1016/j.rser.2013.05.045.
[10] Jacobsson S, Karltorp K. Mechanisms blocking the dynamics of the European offshore wind energy innovation system–challenges for policy intervention. Energy Policy 2013;2010:1–14. http://dx.doi.org/10.1016/j.enpol.2013.08.077.
[11] European Energy Research Alliance. EERA Joint Programme Wind Energy; 2014.
[12] European Wind Energy Technology Platform. Strategic Research Agenda / Market Deployment Strategy (SRA/MDS); 2014.
[13] International Electrotechnical Commission. Technical Committee 88 Wind Turbines Dashboard; 2014.
[14] Markard J, Truffer B. Technological innovation systems and the multi-level perspective: towards an integrated framework. Res Policy 2008;37:596–615. http://dx.doi.org/10.1016/j.respol.2008.01.004.
[15] Bergek A, Hekkert M, Jacobsson S. Functions in innovation systems: a framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers. Innov a Low Carbon Econ Econ Inst Manag Approaches 2008:79.
[16] Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM. Functions of innovation systems: a new approach for analysing technological change. Technol Forecast Soc Change 2007;74:413–32. http://dx.doi.org/10.1016/j.techfore.2006.03.002.
[17] Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res Policy 2008;37:407–29.
[18] Andersen AD, Andersen PD. Innovation system foresight. Technol Forecast Soc Change 2014;88:276–86. http://dx.doi.org/10.1016/j.techfore.2014.06.016.
[19] Foray D, Goddard J, Beldarrain XG, Landabaso M, McCann P, Morgan K. et al. Guide to Research and Innovation Strategies for Smart Specialization (RIS3); 2012.
[20] Foray D, David PA, Hall BH. Smart specialization From academic idea to political instrument, the surprising career of a concept and the difficulties involved in its implementation. Lausanne.
[21] McCann P, Ortega-Argilés R. Smart specialization, regional growth and applications to European union cohesion policy. Reg Stud 2013:1–12. http://dx.doi.org/10.1080/00343404.2013.799769.
[22] Boschma R. Constructing regional advantage and smart specialisation: comparison of two European policy concepts. Sci Reg 2014;13:51–68. http://dx.doi.org/10.3280/SCRE2014-001004.
[23] Foray D. From smart specialisation to smart specialisation policy. Eur J Innov Manag 2014;17:492–507. http://dx.doi.org/10.1108/EJIM-09-2014-0096.
[24] Grillitsch M. Institutions, smart specialisation dynamics and policy. Environ Plan C Gov Policy 2016;34:22–37. http://dx.doi.org/10.1177/0263774×15614694.
[25] Andersen PD, Andersen AD, Jensen PA, Rasmussen B. Sectoral innovation system foresight in practice: nordic facilities management foresight. Futures 2014;61:33–44. http://dx.doi.org/10.1016/j.futures.2014.04.012.
[26] Dufva M, Ahlqvist T. Elements in the construction of future-orientation: a systems view of foresight. Futures 2015;73:112–25. http://dx.doi.org/10.1016/j.futures.2015.08.006.
[27] Smits R, Kuhlmann S. The rise of systemic instruments in innovation policy. Int J Foresight Innov Policy 2004;1:4. http://dx.doi.org/10.1504/IJFIP.2004.004621.
[28] Alkemade F, Kleinschmidt C, Hekkert M. Analysing emerging innovation systems: a functions approach to foresight. Int J Foresight Innov Policy 2007;3:139–68.
[29] Cagnin C, Amanatidou E, Keenan M. Orienting European innovation systems towards grand challenges and the roles that FTA can play. Sci Public Policy 2012;39:140–52.
[30] Martin BR, Johnston R. Technology foresight for wiring up the national innovation system. Technol Forecast Soc Change 1999;60:37–54. http://dx.doi.org/10.1016/S0040-1625(98)00022-5.
[31] Markard J, Stadelmann M, Truffer B. Prospective analysis of technological innovation systems: identifying technological and organizational development options for biogas in Switzerland. Res Policy 2009;38:655–67. http://dx.doi.org/10.1016/j.respol.2009.01.013.
[32] Dachs B, Weber M. Sectoral Innovation Foresight Textiles and Clothing Sector. Europe INNOVA; 2010. ⟨Www.europe-Innova.eu/web/guest/sectoral-Innovation-Watch/publications-Tools⟩.
[33] Piirainen KA, Tanner AN, Alkærsig L. Regional foresight and dynamics of smart specialization: a typology of regional diversification patterns. Technol Forecast Soc Change 2017;115:289–300. http://dx.doi.org/10.1016/j.techfore.2016.06.027.
[34] Börjeson L, Höjer M, Dreborg K-H, Ekvall T, Finnveden G. Scenario types and techniques: towards a user's guide. Futures 2006;38:723–39. http://dx.doi.org/10.1016/j.futures.2005.12.002.
[35] Robinson JB. Energy backcasting: a proposed method of policy analysis. Energy Policy 1982;10:337–44. http://dx.doi.org/10.1016/0301-4215(82)90048-9.
[36] Dosi G. Sources, procedures, and microeconomic effects of innovation. J Econ Lit 1988;26:1120–71.
[37] Piirainen KA, Gonzalez RA. Theory of and within foresight — "What does a theory of foresight even mean?". Technol Forecast Soc Change 2015;96:191–201. http://dx.doi.org/10.1016/j.techfore.2015.03.003.
[38] Barré R. Foresight and their themes: analysis, typology and perspectives. role foresight SelRes. policy priorities. Seville, Spain: European Commission; 2002.
[39] Cariola M, Rolfo S. Evolution in the rationales of foresight in Europe. Futures 2004;36:1063–75. http://dx.doi.org/10.1016/j.futures.2004.03.010.
[40] Schoen A, Könnölä T, Warnke P, Barré R, Kuhlmann S. Tailoring Foresight to field specificities. Futures 2011;43:232–42. http://dx.doi.org/10.1016/j.futures.2010.11.002.
[41] Smits R, van Merkerk R, Guston DH, Sarewitz D. The Role of Technology Assessment in Systemic Innovation Policy. In: Smits RE, Kuhlmann S, Shapira P, editors. Theory Pract. Innov. Policy An Int. Res. Handb; 2010.
[42] Georghiou L, Cassingena Harper J. From priority-setting to articulation of demand: foresight for research and innovation policy and strategy. Futures 2011;43:243–51. http://dx.doi.org/10.1016/j.futures.2010.11.003.
[43] Luo L, Lacal-Arantegui R, Wieczorek AJ, Negro SO, Harmsen R, Heimeriks GJ. et al. A Systemic Assessment of the European Offshore Wind Innovation United Kingdom Contact information. Luxembourg. doi:http://dx.doi.org/10.2790/58937.
[44] Hekkert M, Negro S, Heimeriks GJ, Harmsen R. Technological Innovation System Analysis: A manual for analyst. NL: Utrech; 2011.
[45] Piirainen KA. The GRIP method for collaborative roadmapping workshops. Proceedings of the 5th International Conference Futur. Technol. Anal. - Engag. today to shape tomorrow, Brussels, BE: European Commission.
[46] Piirainen KA. Joint Action Plan. Copenhagen, DK; 2015.
[47] ECOWindS: The European Clusters for Offshore Wind Servicing; 2013.
[48] Findeisen S, editor. STEPLED- and SWOT analysis of all ECOWindS offshore wind clusters. 2014.
[49] Smith A, Stehly T, Musial W. 2014–2015 Offshore wind technologies market report; 2015.
[50] Wilkes J, Pineda I, Corbetta G. Wind energy scenarios for 2020; 2014.
[51] Navigant BC. World Market Update; 2014.
[52] Kern F, Smith A, Shaw C, Raven RPJM, Verhees B. From laggard to leader: explaining offshore wind developments in the UK. Energy Policy 2014;69:635–46. http://dx.doi.org/10.1016/j.enpol.2014.02.031.
[53] Kern F, Verhees B, Raven RPJM, Smith A. Empowering sustainable niches: comparing UK and Dutch offshore wind developments. Technol Forecast Soc Change 2015. http://dx.doi.org/10.1016/j.techfore.2015.08.004.
[54] Wilson C. Up-scaling, formative phases, and learning in the historical diffusion of energy technologies. Energy Policy 2012;50:81–94. http://dx.doi.org/10.1016/j.enpol.2012.04.077.
[55] EERA. EERA Joint Programme Wind Energy; 2014.
[56] TPWind. Strategic Research Agenda / Market Deployment Strategy (SRA/MDS); 2014.
[57] Megavind. Denmark – Supplier of Competitive Offshore Wind Solutions: Roadmap for Megavind's Strategy for Offshore Wind Research, Development, and Demonstration. Copenhagen, DK; 2013.
[58] IEC. Technical Committee 88 Wind Turbines Dashboard; 2014.
[59] Smits R, Kuhlmann S, Shapira P. The Theory and Practice of Innovation Policy: An International Research Handbook. Edward Elgar; 2010.