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A Systemic Assessment of the European Offshore Wind Innovation

Insights from the Netherlands, Denmark, Germany and the United Kingdom

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1. Introduction

1.1. Rationale and the focus of the study

The development and diffusion of offshore wind energy technology is important for European energy policy. Firstly, there is a large amount of potential; the European Wind Energy Association (EWEA) expects 150 GW of offshore wind capacity to be realized in 2030, which would supply 14% of Europe's electricity demand (EWEA, 2011a). The technical potential of offshore wind is estimated at 5800 GW (EEA, 2009) and allows for even further expansion after 2030. Offshore wind has thus the possibility of becoming an important pillar of the future European energy system, contributing to policy objectives on climate change, energy security, green growth and social progress[1]. Secondly, the technology is in the early stages of technological development and, therefore, many business opportunities can be reaped in this emerging sector. However, a large potential does not automatically lead to a large share in future energy systems; neither does an emergent stage of technological development automatically lead to success for companies and the related economic growth and growth in employment. Innovation and technological change are by definition very uncertain processes. The outcomes are strongly determined by processes of chance and by external events that can hardly be influenced. Nevertheless, the scientific community that studies innovation has shown that a conscious and intelligent management of innovation processes strongly increases the success chances of innovation.

The most important insight that has dominated the field of innovation studies in the recent decades is the fact that innovation is a collective activity and takes place within the context of an 'innovation system'. The success chances of innovations are, to a large extent, determined by how the innovation system is built up and how it functions. Many innovation systems are characterized by flaws that hamper the development and diffusion of innovations. These flaws are often labelled as system failures or system problems. Intelligent innovation policy therefore evaluates how innovation systems are functioning, tries to create insight into the systems' weaknesses and develops policies accordingly.

To increase the success chances of offshore wind technology, both in terms of the share in the future energy system and the economic benefits for businesses, it is necessary to study the innovation system for offshore wind energy, evaluate how the system functions and identify the problems that need to be addressed by policy. There have been a number of models developed to study innovation from various perspectives. In this report we use the Technological Innovation System approach (TIS) and in particular a systemic policy framework (see Annex 1) developed by Utrecht University in the Netherlands in cooperation with other European institutes like Chalmers University in Sweden and EAWAG in Switzerland. We analyse the state of the European offshore wind innovation system at the end of 2011, based on insights from four European countries: the UK, Denmark (DK), the Netherlands (NL) and Germany (DE). The report aims to identify weaknesses that hinder the development of the system and in so doing support national and European policy making in the area of offshore wind energy.

[1] As outlined in the EC Innovation Union http://ec.europa.eu/research/innovation-union/index_en.cfm accessed 27 Apr 2012.

1.2. Methodological aspects

To enable a precise understanding of this report, the reader should be aware of the following methodological issues:

The first issue is the selection of the countries for analysis. At the time of the analysis (end 2011) the four countries that had the largest online offshore wind capacity in Europe were: the UK – 1589 MW, Denmark – 854 MW, the Netherlands – 247 MW and Germany – 195 MW. However, when these numbers are complemented with data on offshore wind capacity *under construction*, *consented* and *planned* till 30 June 2011, the two leading countries became the UK with a total of 48.6 GW and Germany with 31.2 GW. The Netherlands and Denmark with 5992 MW and 2471 MW lose their leading position to countries like Sweden, Norway and France (EWEA, 2011a). For our analysis we decided to focus on the UK, Denmark, the Netherlands and Germany because of the varying strategies that these countries deployed and the different circumstances that led two of them (the UK and Germany) to progress rapidly, and the other two (Denmark and the Netherlands) to lower the speed of their offshore wind development.

Secondly, the report depends to a great extent on the Global Offshore Wind Farms Database 4C (further referred to as *4C database*) version October 2010. We have used this database to map the structure of the four analysed innovation systems, namely the actors, physical infrastructure and capital costs. At the time of the analysis, it was the most recent version of the database available. However, due to the length of time between October 2010 and the end of 2011, there may have been some adjustments to the composition of the innovation systems that are not captured by the database. Another implication of following the 4C database is that if entries are missing in the database, they do not show up in our analysis either. We have chosen not to complement the analysis with the missing data for three reasons:

1. It is expected that the missing data does not alter the main conclusions of our analysis.
2. For methodological consistency we decided to follow one solid source of information.
3. Although this report has been prepared with great care, it is not intend to be exhaustive. Since we aim to present the general view of the analysed systems, we have mapped only the most important actors and circumstances that have had an impact on the development of the four innovation systems.

Thirdly, next to the data obtained from the 4C database and various reports, publications and internet sources, we have carried out a series of interviews with about 30 actors involved in the field. Furthermore, 10 reviewers, engaged in the offshore wind innovation system, have reviewed the earlier draft of this report. The review process was an additional source of qualitative information about how the system functions and what challenges it faces.

Fourthly, as much as it was possible to draw conclusions about nationally delimited TISs in the UK, Denmark, the Netherlands and Germany, our conclusions for the European offshore wind innovation system are purely based on analysis of these four countries.

Finally, the time and resources allocated to this study did not allow for a deeper analysis of e.g. financial infrastructure, soft institutions (such as expectations, promises, routines) or interactions at the level of bi- or tri-lateral collaborations. More in depth interviews would be necessary to acquire this type of information. For the same reasons this report does not present and discuss the design of a systemic instrument that would address the identified weaknesses in the offshore wind innovation system.

1.3. Composition of the report

The report is composed of four sections following the steps as described in the manual for analysts presented in Annex 1. Firstly, in Section 2, we look into the *structure* of the innovation systems in the UK, Denmark, the Netherlands and Germany. In particular we study which actors are involved in the offshore wind systems (actors – section 2.1); how various actors cooperate with each other (networks – section 2.2.); what the national regulatory framework consists of; what the expectations and social acceptance are (institutions – section 2.3); and what the state of the knowledge, physical and financial infrastructure is in the four countries (infrastructure – section 2.4). Secondly, in Section 3 we analyse how the various systems *function*. For that purpose we use a set of seven evaluation criteria that in the literature have been labelled as 'functions of innovation systems'. We analyse each function based on the available data and the insights from 30 stakeholders' interviews and 10 reviews of the draft report. Finally, in Section 4 we identify the system *weaknesses* that block the proper functioning of the offshore wind innovation systems and which, for that reason, require urgent and coordinated policy effort.

1.4. Acknowledgements

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2. Structural analysis

Each innovation system consists of four types of components: actors, networks, institutions and infrastructure (physical, knowledge, financial). In this section we analyse the structure of the UK, Danish, Dutch and German offshore wind Technological Innovation Systems (TIS).

2.1. Actors

Actors through their choices and actions generate, diffuse and utilize technologies. Their presence and capabilities directly or indirectly contribute to the system development as well as influence its pace and direction. According to EWEA (2011b), in 2010 offshore wind energy employed almost 35000 people in Europe (EU-27) directly and indirectly while the installed capacity was 2.94 GW. EWEA expects in its baseline scenario that in 2020 40 GW of offshore wind will be installed requiring 170000 people to work in the field.

In this section we analyse who is involved in the offshore wind innovation system and in what capacity. Five different categories of actors are distinguished and mapped in this report: governmental bodies, knowledge institutes, educational organizations, industry and support organisations. The analysis is not exhaustive. We include only the most important actors that have been involved in the offshore wind innovation systems until 2011. For each national offshore wind innovation system we distinguish between *national actors* (located in the country under study) and *foreign actors* (involved in an offshore wind project in the country under study but not located in that country). The labelling of some of the actors as *national* or *foreign*, especially when they are multinational companies, has been based on whether the company has a subsidiary in the country. For that reason for example Vestas, a Danish company, can also be found in the Dutch value chain or Siemens Wind Power (a subsidiary of the German Siemens) in the Danish value chain.

2.1.1. Governmental agencies

Offshore wind is a relatively new field for the governments in all four analysed countries. The role of the government is broadly the development and administration of legislation, permission procedures and consenting. In various countries different ministries and agencies carry out the specific tasks. Whereas in Denmark all processes are concentrated in one organisation, in the UK many different ministries and governmental agencies are responsible for different aspects of the offshore wind procedure. Also in Germany, there are a large number of authorities involved in the offshore wind procedures, but the German government is working on combining the licensing for offshore wind farms into a single procedure. From the perspective of the European offshore wind innovation system, the involvement of a great number of national governmental agencies in the administration of offshore wind process is not very efficient for its development and may need to be reduced. Table 1 presents an overview of

Whereas in Denmark the entire process is governed by one agency, in the UK, the Netherlands and Germany many different ministries are responsible for different aspects of the offshore wind procedure governmental bodies that deal with offshore wind in the UK, Denmark, the Netherlands and Germany and the National TSO's (Transmission System Operators).

Table 1. Overview of TSOs and governmental bodies relevant for offshore wind

Country	TSO	Governmental organisation	Responsibility
UK	- National Grid plc - System Operator for Northern Ireland (SONI) - Scottish and Southern Energy (SSE) - Scottish Power Transmission plc	- The Crown Estate	Owner of the seabed - any offshore wind farm needs a Crown Estate lease
		- Department of Energy and Climate Change (DECC, formerly: DTI) - Scottish Government - The Department of Enterprise, Trade and Investment (DETI)	Introduction of the Renewable Obligation (RO) Scheme
		- Office of Gas and Electricity Management (OFGEM) - Northern Ireland Authority for Utility Regulation	Accreditation of Renewable Obligation Certificates
		- Secretary of State for Energy and Climate Change (England and Wales[2]) - Minister for the Environment (Northern Ireland) - Scottish Minister for Enterprise, Energy & Tourism - Marine Management Organisation (MMO)[3]	Consents (legal, building, spatial planning)
		- MMO (England and Wales) - Northern Ireland Department	Consents (legal, building, spatial planning)
Denmark	- Energinet.dk	- Danish Energy Agency under responsibility of Climate and Energy Ministry	Developing and administering legislation, tenders for offshore wind farms, consents (legal, building, spatial planning) and grid connection authorisation
Netherlands	- TenneT B.V.	- Ministry of Economic Affairs, Agriculture and Innovation	Subsidy Sustainable Energy (SDE) and electrical infrastructure
		- The Ministry of Infrastructure and the Environment	Consents (legal, building, spatial planning in the North Sea) and allocation of environmental permits
		- AgencyNL	Revenue approval (tender) and revenue execution (offshore wind subsidy scheme and tax related policy)

[2] Unless consented by Welsh Ministers under the Transport & Works Act.
[3] Ibid.

Germany	- EnBW Transportnetze AG - TenneT TSO GmbH - Amprion GmbH (formerly RWE) - Transportnetz Strom GmbH	- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) - Federal Ministry of Transport, Building and Urban Affairs (BMVBS) - Federal Maritime and Hydrographic Authority (BSH)	Developing and administering legislation, tenders for offshore wind farms, consents (legal, building, spatial planning) and grid connection authorisation
		- Federal authority for nature conservation (BfN)	Environmental permits allocation
		- Federal Grid Agency	Revenue execution: FGA is the supervising authority for the feed-in tariff (reports to BMU who monitors the law)

2.1.2. Knowledge institutes

Knowledge institutes include universities, technology centres, research centres and institutes. Consultancies are included in the support organisations category.

The purpose of this section is to identify the main knowledge institutes that perform research on offshore wind in the four analysed countries[4]. For that purpose we screened journal publications, as archived in the Web of Science from Thomson Scientific between 1994 and 2010, with *offshore wind* as a topic indication. We summarised major results of our research in Table 2. This table presents: (i) the total number of knowledge institutes per country, (ii) the total number of publications on offshore wind per analysed country, and (iii) the top three organisations publishing in the field per country including the number of publications per institute and the national percentage (between brackets).

Table 2. Number of knowledge institutes and scientific publications on offshore wind by the UK, Danish, Dutch and German actors (1994-2010)[5]

Country	Total no of organizations	Total no of publications	Most important organizations (incl. number of publications and national percentage)
UK	170	451	Univ Durham (21, 5 %) Univ Strathclyde Scotland (18, 4%) Univ Oxford (16, 4%)
Denmark	66	236	Risø Natl Lab (68, 29%) Univ Aalborg (33, 14%) Tech Univ Denmark (32, 14%)
Netherlands	43	140	Delft Univ Technol (44, 31%) Univ Utrecht (13,9%) ECN (13, 9%)
Germany	194	426	Univ Bremen (28, 7%) Leibniz Univ Hannover (23, 5%) Alfred Wegener Inst Polar & Marine Res (22, 5%)

[4] The impact of produced knowledge (both codified and tacit) is discussed in section 2.4.1 (knowledge infrastructure).
[5] A note on multi-organisation papers: a joint paper by two research organisations from the same country is computed once in the country profile and once for each of the author organisations.

Our analysis shows that the total number of knowledge institutes involved in publishing in both Denmark (66) and the Netherlands (43) is much lower than in Germany (194) and the UK (170). However, the Danish and the Dutch knowledge institutes rank highest internationally in terms of the number of publications on offshore wind. In particular, the Danish Risø National Lab for Sustainable Energy and the Dutch Delft University of Technology (TU Delft) excel in their number of journal articles per institute (68 and 44 respectively). Risø ranks 6th while TU Delft is 13th in the world (Web of Science, Thompson Scientific). Two other Danish universities follow Risø and TU Delft: Aalborg University (33 publications) and Technical University Denmark (DTU) (32 articles).

Public research organisations lead in publishing on offshore wind. Particularly Risø and TU Delft

In Germany knowledge institutes involved in the field specialise in different aspects of offshore wind technology. Most well known for its track record in the field is the University of Bremen. It specialises in material science and production engineering and with 28 articles on offshore wind it ranks 23rd worldwide. Bremen is followed by Leibniz University Hannover (23 papers) on developing systems for determining physical parameters for offshore wind farms and the Alfred Wegener Institute for Polar and Marine Research (22 articles), which specialises in research on integrating aquaculture in offshore wind farms and the impact of offshore wind farms on the marine environment.

In the UK the production of scientific codified knowledge is very scattered, and the UK knowledge institutes rank lowest of all four analysed countries in terms of publications on offshore wind. The highest ranked UK organisation and only one that has more than 20 publications is Durham University (41st worldwide). The Energy Group of the School of Engineering and Computing Sciences is particularly active in research associated with the commercial development of wind power and especially the reliability and condition monitoring of 2-10 MW wind turbines. Durham University is followed by Strathclyde University in Scotland (18 articles) and Oxford University (16 articles). All remaining UK organisations score below 20 papers with very many of the institutes having only 1 or 2 publications.

There are less Danish and Dutch knowledge institutes than in Germany and the UK but they publish most in the international context

2.1.3. Educational organisations

The list of educational organizations delivering courses dedicated to renewable energy, and wind in particular, is long and growing in both educational categories: vocational and academic. However, only a small number of programmes specialize in the particular needs of the offshore wind sector. Table 3 presents an overview of major educational organisations that offer courses on renewables that are relevant for

Offshore wind educational courses are few and recently developed the offshore wind sector. This overview does not include organisations that offer individually arranged education (such as PhDs).

Table 3. Organizations offering renewable energy courses relevant for offshore wind field[6]

Country	Vocational courses	Academic/ Polytechnic BSC level	Academic/ Polytechnic MSc level	Academic/ Polytechnic PhD
UK	Nat Ren Energy Centre (NAREC) Northumberland College Lowesift College* Falk Nutec* East Coast Training Services* Siemens*	Univ of Exeter Univ of Cumbria* Univ of Birmingham Univ of Nottingham Univ of Dundee*	Cranfield University* Loughborough Univ Swansea Univ Univ of Birmingham Univ of Centr Lancashire Univ of Dundee* Univ of Edinburgh* Univ of Exeter* Univ of Leeds Univ of Nottingham	UK Energy Research Center* Univ of Dundee* Univ of Central Lancashire* University of Strathclyde*
Denmark	Danish Univ Wind Energy Training (DUWET)* Offshore Center Denmark* Survival Training Center* AMU-Vest* Falck Nutec* Maersk Training Centre A/S* EUC Vest* Danish Wind Power Academy*	Business Academy South-West*	Aalborg Univ* Techn Univ Denmark*	Risø * Techn Univ Denmark*
Nether-lands	Hoogeschool van Arnhem and Nijmegen (HAN)* Maritime Campus NL* NHL* ROC Kop Noord Holland* DUWIND* DHTC* Ascent Safety* Van Oord Academy* Hogeschool Den Bosch	Delft Univ of Techn* (HAN)* Outsmart*	Delft Univ of Techn*	Delft Univ of Techn*
Germany	Education Centre for Renewable Energies (BZEE)* Ren Agency RENAC Deutsches Wind Energy Institute ForWind* Edwin Academy Univ of Kassel Deutsche WindGuard* Falck Nutec*		Aachen Univ of Applied Sciences Univ of Applied Sciences Bremerhaven Univ of Flensburg Univ of Hanover Univ of Kiel Univ of Oldenburg Univ of Applied Sciences Hamburg Univ of Applied	Oldenburg Univ Univ Stuttgart* Vestas (professorship)* Schleswig Holstein (professorship)* Univ of Applied Sciences Hamburg

[6] Based on Wind Power Offshore Careers Guide (2012) and websites of the organizations accessed on 2 Feb 2012.

	Moog		Sciences Saarbrücken	
European/ International	GL Garrad Hassan* World Wide Energy Institute		European wind energy Master (EWEM) (4 techn Univ in North Europe)* EUREC & 8 Univ Siemens* European Academy of Wind Energy EAWE*	

(*) Denotes that the organisation gives a dedicated offshore wind module, specialization or introduction within their educational programmes portfolio

Academic and polytechnic training in offshore wind in Denmark and the Netherlands is, as in the case of research, concentrated in a comparatively small number of organisations, namely at DTU, Risø and Aalborg University in Denmark and TU Delft in the Netherlands. These organisations have been the forerunners in enrolling and releasing yearly a number of individual master and PhD graduates with a specialisation in various aspects of offshore wind. They also give annual dedicated master programmes with focus on- or with specialisation in- offshore wind technology.

Denmark and the Netherlands are frontrunners in academic and polytechnic training in offshore wind. Germany and the UK are catching up in expectation of rapid market development

Germany and the UK do not have a very long tradition in offering education in offshore wind energy. However, since both countries are expected to lead European offshore wind development in the coming years (EWEA, 2011a) they have taken serious measures to address the demand voiced by industry, especially for qualified engineers. For example, in 2011, £6.5 million was allocated to engineering education in the UK in the hope of ushering in a generation of competent renewable energy workers. As a result, several UK universities (University of Edinburgh, Strathclyde and Exeter) have been preparing doctorate programmes starting in 2012 for up to 50 engineering students in technical aspects, as well as, in business and economics of offshore wind energy. In Germany, the Education Centre for Renewable Energies (BZEE) recently developed a qualification programme dedicated to the service and maintenance of offshore wind farms. Vestas provided funding for a new endowed professorship for wind energy technology, to be based at Flensburg University of Applied Sciences on the basis of a public-private partnership (Vestas, 2010[7]). A great number of master and bachelor courses as well as individually arranged PhDs are expected at many German and the UK universities in 2012. Most of these courses are not dedicated offshore wind programmes. Offshore wind constitutes only a part of the renewable technology educational portfolio of the educational organisations. Many of these courses have a strong focus on the technical aspects of offshore wind energy.

Vocational training is offered mainly by companies and often by those serving offshore industry

A growing number of vocational courses are offered in all four of the analysed countries. Contrary to the

[7] http://www.vestas.com/Files/Billeder/countrysites/Germany/wind10_ENG.pdf, accessed 2 Feb 2012.

academic education, vocational training is mainly given by companies or is results from collaboration between industry, government bodies and knowledge institutes. For example as the outcome of such a partnership, NAREC, the UK National Renewable Energy Centre for renewable energy development and testing, has opened a new training tower which is designed to provide academic and industrial training programmes for technicians in the wind industry. The programme has a strong focus on the offshore sector. Furthermore, many vocational courses are given by training centers assisting the oil and gas industry. These are mainly health, safety, survival and environment courses and they serve well the transfer of skills from the oil and gas sector to the offshore wind sector. Some of them, such as, for example one given by the German GL Garrad Hassan, are now internationally known. At the European level, the European Academy of Wind Energy (EAWE) provides many courses on offshore wind. EAWE is a registered body of research institutes and universities in Europe (the UK, Denmark, the Netherlands and Germany included) working on wind energy research and development. The aim of EAWE is twofold: to be a world leading wind energy academic and research community; and maintaining Europe at the forefront of wind energy pre-competitive innovation (EAWE, 2012[8]) worldwide. European Wind Energy MSc (EWEM) within Erasmus Mundus is another pan-European master programme run by TU Delft, DTU, Norwegian University of Science and Technology, and the Carl von Ossietzky University Oldenburg. EWEM aims to educate 120-150 MSc graduates per year, covering the top 1-2% global demand for wind energy professionals with a post-graduate education[9]. Finally, the POWER Cluster project (Pushing Offshore Wind Energy Regions) comprising of eighteen partners from six countries (the UK, Denmark, the Netherlands, Germany, Norway and Sweden) and its sister project 'South Baltic Offshore Wind Energy Regions' (due in 2013), have both been promoting the enhancement of educational possibilities in offshore wind.

Countries in Europe cooperate on providing integrated trainings related with offshore wind such as EAWE and

2.1.4. Industrial actors

To illustrate the involvement of the key industrial actors in the UK, Danish, Dutch and German offshore wind systems we use a value chain consisting of three broad steps. The first step is the development of the wind farms and it encompasses such actor categories as owners, project developers and managers of the farms. The second step is the construction phase, which includes installation contractors, component manufacturers and substation developers/suppliers. The third step is the operation and maintenance (O&M) covering all actors involved in the user phase of the farms. The following eight figures (Figures 1-8) present value chains of the four countries under study. In the first four (Figures 1-4) the focus is on showing the involvement of national actors in both national and international projects (actors' perspective). Figures 5-8 show which actors (national or international) build national wind farms (wind farms' perspective). As a source of data we use the 4C database (version October 2010). In case of multinational organisation we include it as a national actor whenever the company has subsidiaries in the country. For that reason, e.g. Vestas, can be found in the Dutch value chain while Siemens Wind Power in the Danish value chain. Given the geographical scope of this report and to keep clarity of the figures, the *international* category comprises of companies from the four analysed countries. That

[8] www.eawe.eu accessed 2 Feb 2012.
[9] www.windenergymaster.eu accessed 2 Feb 2012.

means we do not list there companies from e.g. Belgium, the US or Spain. By *project* we mean a *wind farm*.

Actors' perspective

Figure 1. Dutch actors involved in the national and international projects along the value chain[10]

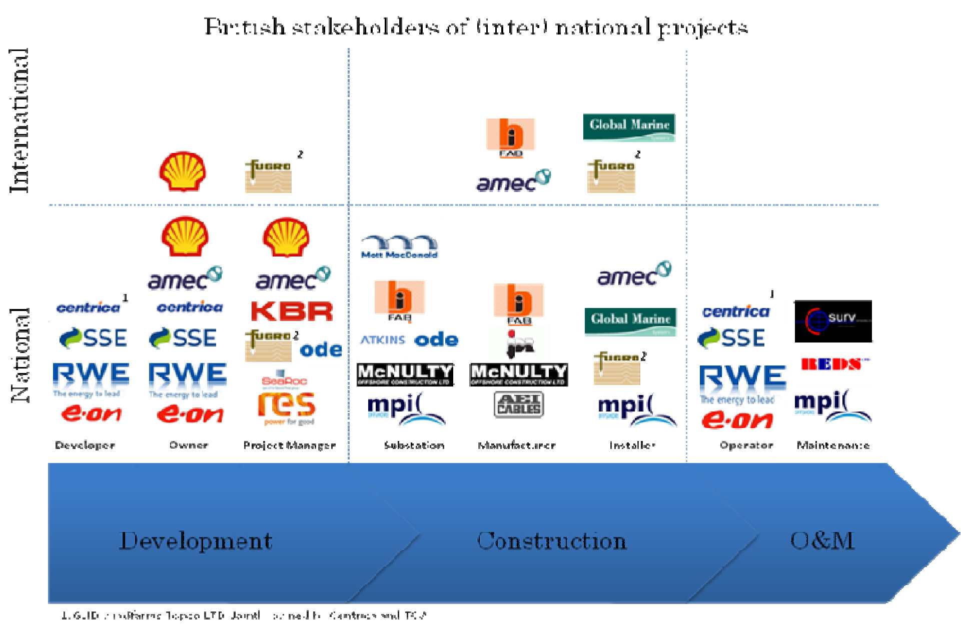

Figure 2. The UK actors involved in the national and international projects along the value chain[11]

[10] One of the missing Dutch companies in the 4C database and in this figure is Econcern/Evelop. The company developed projects in UK (1), Belgium (1) and Germany (4) but went bankrupt and does not exist anymore (Ernst van Zuijlen, 2012).

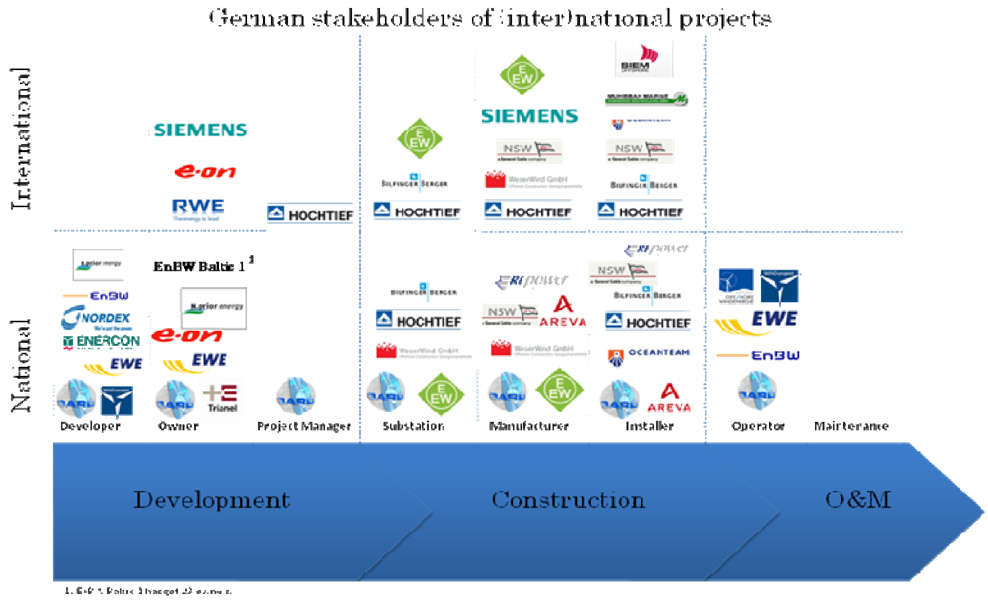

Figure 3. German actors involved in the national and international projects along the value chain[12]

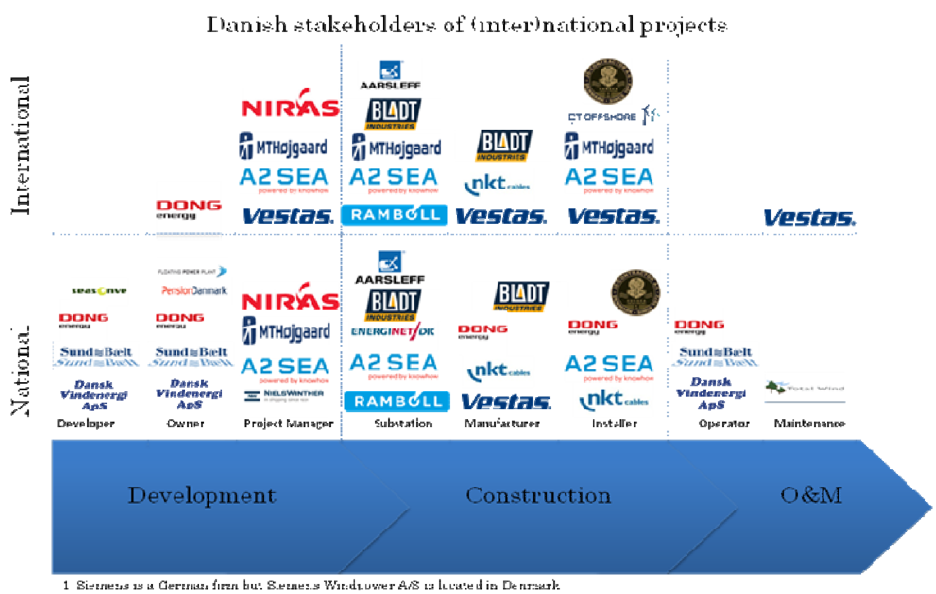

Figure 4. Danish actors involved in the national and international projects along the value chain[13]

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[11] Missing in the 4C database and on this figure are foreign developers active in the UK such as WPD (DE) and Dong (DK). Also the SSE (UK) is active in the Netherlands but not mentioned under 'international' (Ernst van Zuijlen, 2012).

[12] Examples of companies that are not included in the 4C database and thus do not show up on this figure are: Aerodyn Energiesysteme (technology developer); RENK, Bosch-Rexroth and Winergy (suppliers of wind turbine gearboxes and additional components); Weier and VEM Sachsenwerk (generator suppliers), Schaeffler (FAG), Liebherr, IMO (bearing suppliers); Siempelkamp and MAN (heavy castings (hubs, bed frames, and main shafts) suppliers) (Eize de Vries, 2012).

As shown in Figures 1-4, the value chains in the four analysed countries are relatively complete with a variety of competent actors. Both incumbents[14] as well as new entrants can be identified in all four countries.

Contrary to the UK, the Dutch companies are very internationally oriented

There are more Dutch companies, especially construction firms, present in the foreign value chains than the UK, Danish and German firms. Moreover, contrary to the UK, a greater number of Dutch companies are involved in international rather than domestic projects. This implies that the Netherlands has got a very well developed national construction (foundations, substations, and wind farm installation) industry (supply) and, as a consequence of national policy, a small home market (demand). The involvement of Danish and German companies in national and international projects is relatively equally spread.

The development, ownership, operation and management of wind farms is mostly performed by national companies

The development, operation and management of wind farms are predominantly done by national companies. The same can be said about the ownership of the projects. In all analysed countries there is a strong focus on ownership of national farms rather than international establishments. Furthermore, as shown in the figures (1-4) large utilities such as Nuon, Eneco, E-on, Centrica, RWE, Vattenfall, Dong Energy dominate as owners, developers and operators of the farms. This dominance is observable mostly in the UK (Markard and Petersen, 2010) and least in Germany where only 39% of approved offshore wind projects are owned by large utilities. The remaining shares in German wind farms are held by a great number of developers, financial investors and municipal utilities (KPMG, 2010). As such, Germany can be characterised by a more dispersed wind farm ownership structure compared to the UK, Denmark and the Netherlands.

Large utilities dominate as owners, developers and operators particularly in the UK

What is also noticeable in the four figures (1-4) is that there are a few established and financially stable oil and gas multinationals involved in offshore wind such as, Dutch van Oord and Shell (NL), Amec (UK) or

Many established offshore firms are present in the UK, Danish, Dutch and German

[13] Missing companies are: Semco Maritime (Substation), Apro (Maintenance), LM Wind (Manufacturer), COWI (Substation), Grontmij, Carl Bro A/S (Substation), VSB Industri- og Stålmontage A/S (Manufacturer), Blue Water Shipping (Installer and Maintenance), Envision Energy (Chinese owned, but with development department in Denmark where they work on their new offshore tubine), Fyns Kran Udstyr (Manufacturer), Q-STAR ENERGY A/S (Maintenance), SubCPartner (Manufacturer and Maintenance), Knud E. Hansen A/S (Installer) (Morten Holmager, 2012).

[14] Incumbent in innovation studies denotes an existing, usually large, company that has stable position on the market.

RWE (DE). Their involvement in the offshore wind may suggest that they are ready to expand their business into new fields. From an innovation perspective, involvement of such companies (incumbents) effectively serves the purposes of knowledge cross-fertilisation, investor confidence and eventually the expansion of the offshore wind market.

Wind farms' perspective

In the following set of figures (Figures 5-8) we show which actors are involved in the development, construction and operation of national wind farms in the four analysed countries. What is clear is that even though the national wind farms are mostly owned and managed domestically, rarely are they constructed solely by national companies. The UK innovation system especially seems most open to foreign actors. As shown in Figure 6, there are more non-UK than UK companies all along the UK value chain. This is not surprising. The UK, unlike Germany and Denmark, does not have a single manufacturer of the required 3–7 MW+ wind turbines. Also, the supply chain for local components is small and not very complete (Eize de Vries, 2012), while in 2010/11 the UK had the highest installed capacity and more offshore wind farms than any other European country. That indicates that the UK has got a developed market (demand) but a small national industry (supply) (Douglas Westwood, 2010).

> *The UK innovation system is most open to foreign actors of all four systems*

With regards to suppliers of technology and in particular wind turbine manufacturers, Siemens and Vestas dominate in Europe, having supplied respectively 51% and 39% of installations in 2011. These two companies are followed by REpower[15] (3%), Areva (<1%) and Bard (1%) (Wind directions, 2012). EWEA (2011a) lists also a number of new entrants to the offshore turbine manufacturing business, such as Bard and Nordex (DE), who both develop large 6 MW+ wind turbines although with very different fate. Other newcomers from outside of the four analysed countries but important for the entire European offshore wind innovation system include: Alstom, AMSC, Condor, DSME, Envision, Gamesa, GE, Goldwind, Northern Power Systems, Samsung, SCD (Ming Yang), Sinovel, Hyunday and XEMC–Darwind (Eize de Vries, 2012; Ernst van Zuijlen, 2012).

> *Manufacturing of turbines and supply of substructures observe an increase of new entrants*

Similarly, the substructure supply is dominated by established suppliers such as BiFAB (UK), Bladt (DK) and Sif and Smulders (NL); with a number of new entrants such as Heerema (NL) and EEW, Strabag and Weserwind (DE) (EWEA, 2011a). Presence of new entrants in the system is important for increased levels of competition and technology price stabilisation. Their emergence indicates that the relatively complete value chains are also quite dynamic.

[15] With major shares of Shuzlon (India).

The range of subsea high voltage cable suppliers is limited and none of the established suppliers are located in the analysed countries: Swiss/Swedish ABB, French Nexans and Italian Prysmian. German NKT and General Cable are the only new entrants to high voltage cable market.

There are few new entrants in the area of high voltage subsea cables

The leading suppliers of vessels in Europe are Danish A2Sea and Dutch Ballast Nedam, Seaway Heavy Lifting and Jumbo and the UK (MPI Offshore, Seajacks) and according to (EWEA, 2011a) there are hardly any new entrants in this field and none from any of the four analysed countries. However, according to Bloomberg New Energy Finance (2012), 11 new vessels are programmed to start operating in Europe in 2012 and will work on 10 offshore wind farms[16]. If the new vessels fail to start operating while the field develops further, the current cable and vessels suppliers may face manufacturing capacity limits (EWEA, 2011a).

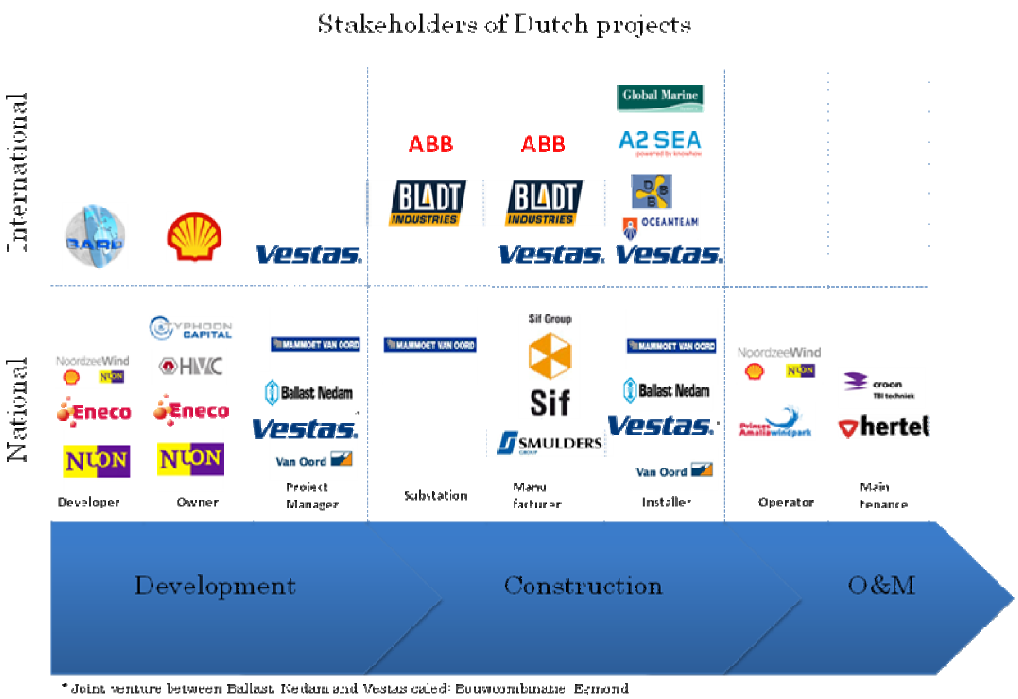

Figure 5. Dutch and international actors involved in the Dutch projects along the value chain

[16] Offshore Wind Market Outlook, 13.01.12, http://www.docin.com/p-194017138.html accessed 27 Apr 2012.

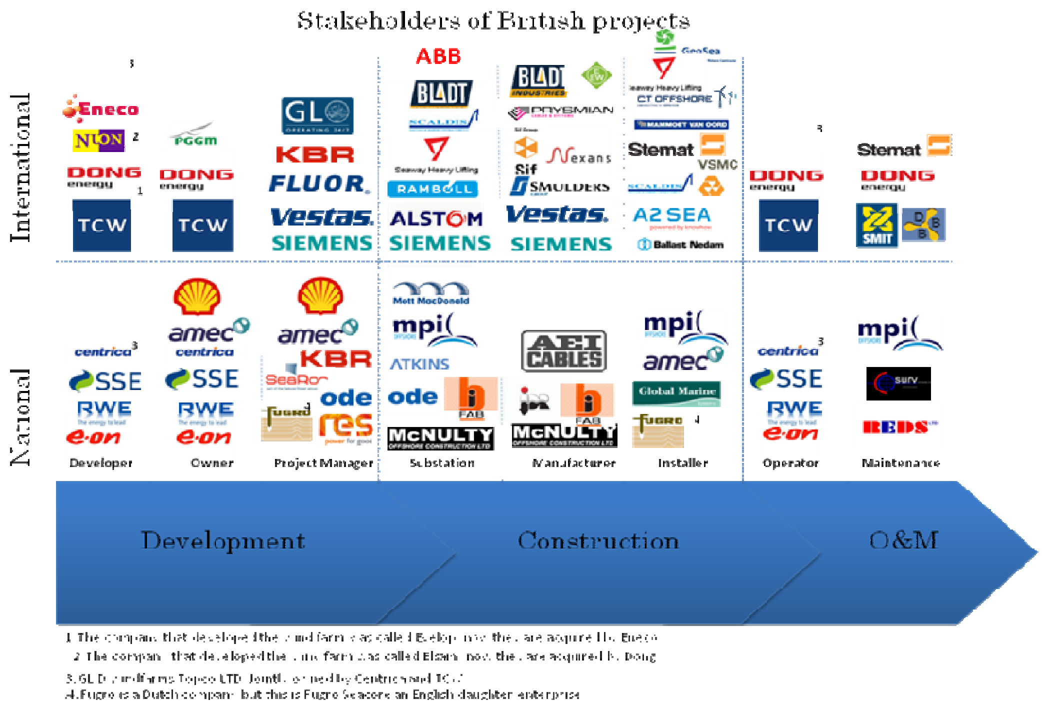

Figure 6. The UK and international actors involved in the UK projects along the value chain

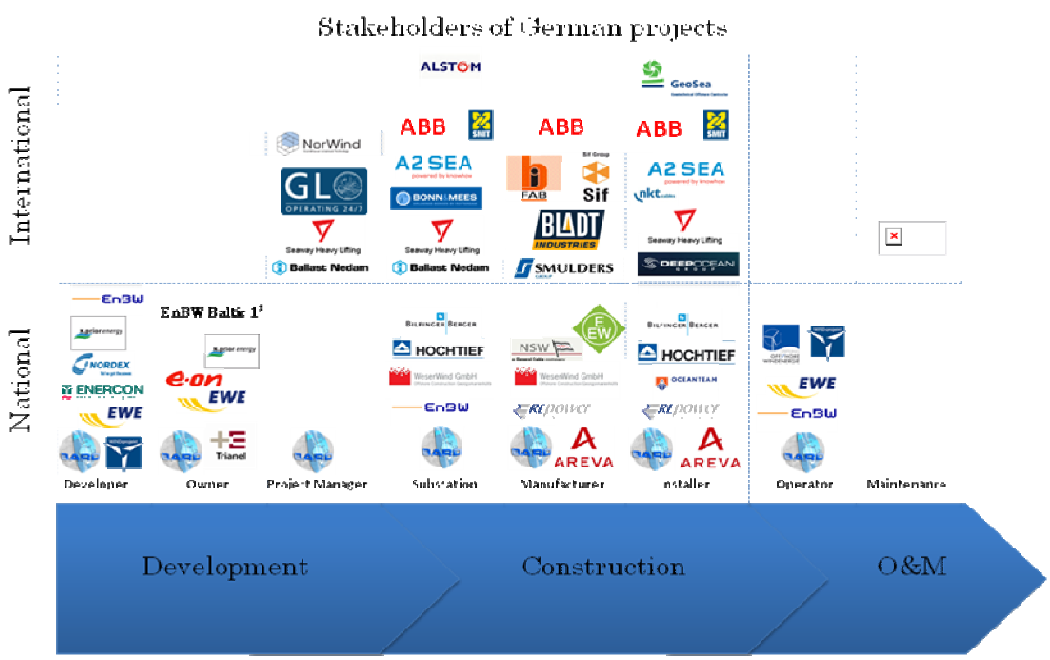

Figure 7. German and international actors involved in the German projects along the value chain

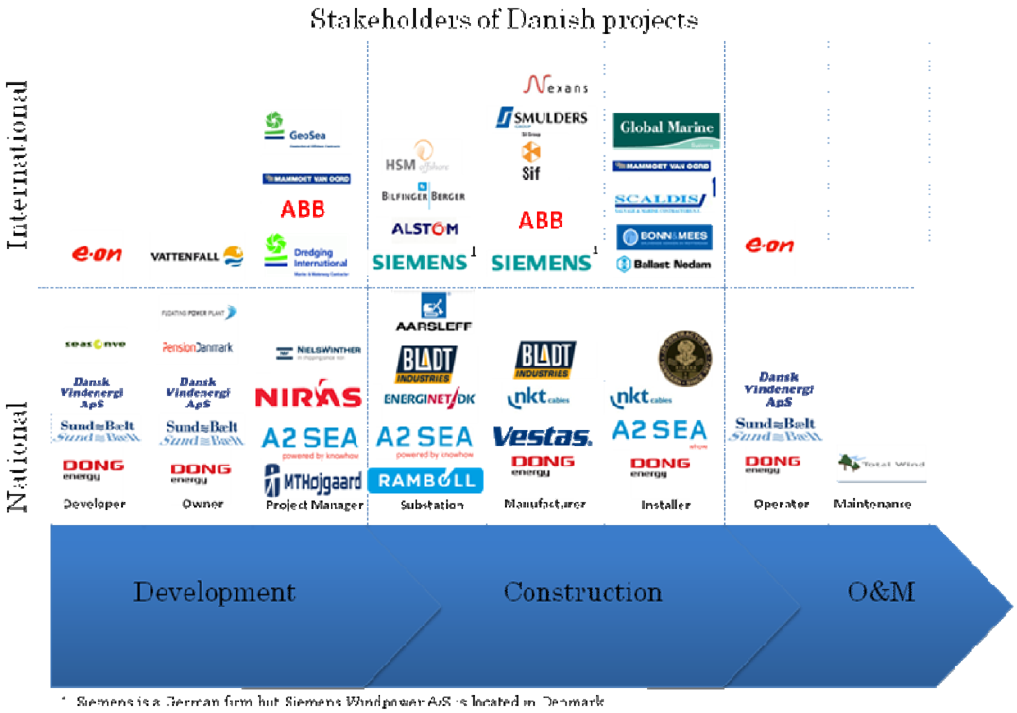

Figure 8. Danish and international actors involved in the Danish projects along the value chain

Furthermore, although the Dutch companies are main suppliers of vessels (they own a total of 20 vessels compared to Danish owning 10 vessels) (Athanasia Arapogianni, 2012), it is the Danish companies that are in the lead in terms of heavy vessel *installation* contracts in Europe (see Figure 9). Figure 9 also shows that the UK is the main *installer* of subsea cables.

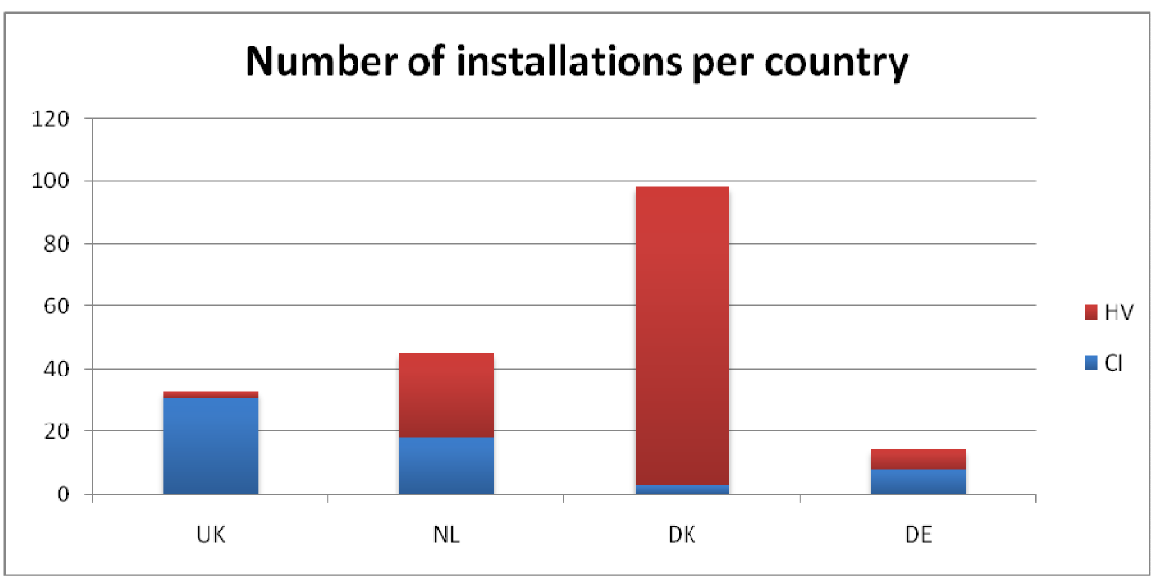

Figure 9. Number of cable installation (CI) and heavy vessel (HV) projects per country according to 4C Database (October 2010)

2.1.5. Support organisations

Support organisations are all organisations that are not covered by the above categories but that in some capacity do contribute to the development of the TIS. These are legal organisations, financial organisations/banks, intermediaries, knowledge brokers and consultancies. Table 4 shows the involvement of banks and consultancies in the offshore wind projects in the four analysed countries.

Table 4. Overview of the most active offshore wind support organisations in the UK, Denmark, the Netherlands and Germany.

Country	Financial organisations	National consultancies
UK	Lloyds Banking Group, Santander, UK's Green Investment Bank, Centrica Energy	ABP Marine Environmental Research Ltd (ABPmer), Anatec Ltd (12*), Atkins BMT Renewables Bomel Limited Bond Pearce (2), Dynpos Ltd, Gardline Environmental Limited (GEL) (3), Gardline Hydro GL, Garrad Hassan and Partners Ltd, Global Marine Systems Lt, HR Wallingford UK Ltd (2), Marine Ecological Survey (MES), MeteoGroup UK Metoc Plc (2), Mott MacDonald (7), Mwaves Ltd (2), Natural Power Consultants Ltd (2), NFFO Services Limited (7), Ocean Marine Services Ltd (4), Offshore Design Engineering (ODE) Ltd (3), PMSS (26), Royal Haskoning (2), RPS Group Plc Searoc UK LTD, SEtech (Geotechnical Engineers) Ltd (10), Siemens Transmission and Distribution Ltd (3), Titan Environmental Surveys (3), Warwick Energy Limited
Denmark	Danish Eksport Kredit Fonden, Nordic Investment Bank, Kirsten Gosvig's pension fund, Pension Danmark, Brancor Capital Partners	Spok ApS, NIRAS (22), Ramboll, COWI, Dansk IngeniørService A/S, Esbjerg Safety Consult A/S, Grontmij, HH-Consult A/S, LICengineering A/S, Orbicon A/S[17]
Netherlands[18]	Rabobank, ASN bank, Triodos bank (managing PGGM and Ampere Equity Fund), ING, Typhoon Offshore	BMO Offshore, Ecofys (6), Grontmij (4), Kema, Marin, Deltares, Mecal, TU Delft Wind Energy Research Institute DUWind (7), Profin Sustainable Energy Solutions BV, OutSmart, Quality in Wind, BLIX, Rotation Consultancy
Germany	Commerzbank, KfW incl national branches, IPEX-Bank, Siemens Bank, Euler Hermes export credit agency, RWE Innogy, Deutsche Bank, Unikredit Munich, Nord LB, NRW Bank, Helaba, HSH Nord Bank AG, Windreich AG	Germanischer Lloyd Industrial Services GmbH, GL Garrad Hassan Deutschland GmbH, OECOS GmbH, SGS-International Certification Services GmbH (7), Siemens AG
European	European Investment Bank, Société Générale S.A.	

* The number next to the name indicates the number of contracts they worked on.

For long, the most frequent way of financing the offshore wind farms has been by including them in the balance sheet of the utilities (Guillet, 2011). The balance sheets are relatively strong but increasingly not sufficient forcing project developers to acquire funds from banks and investment companies. Due to the financial crisis and more limited access to capital, banks reduced their renewable energy projects funds, hence, a growing number of banks are needed for the financing of one wind farm. Despite of that, EWEA (2011c)

[17] Morten Holmager, 2012.
[18] http://www.nwea.nl/hollandsgloriewindopzee accessed 27 Apr 2012.

reports that the number of banks willing to take offshore wind risk is growing steadily. More than 20 organisations have by now (2011) obtained firm credit committee approval to take offshore wind risk. Increasingly, Japanese banks working from the UK have become involved in financing the European offshore wind activities (Michiel van Heemskerk, 2012).

Consultancies involved in the offshore wind field in Denmark, the Netherlands and Germany are fewer than in the UK. The large number of UK consultancies might be due to a certain consultancy culture (Roberto Lacal-Arántegui, 2012) and a reaction to: the rapidly growing offshore wind market, the increasing number of new projects and the rising demand for specialised advice in the absence of strong, university-based and engineering knowledge on offshore wind.

Great number of consultancies in the UK may be a reaction to the rapidly growing offshore wind market in the absence of well developed university-based and engineering knowledge

There are no specific legal organisations solely devoted to offshore wind in the analysed countries; each company deals with its own legal issues. For the wind farms it is the project developers who are responsible for acquiring all permits and assessments, as well as for ensuring legal compliance for the farms' construction.

2.2. Networks

While the presence and the capacities to innovate of various actors are very important for the functioning of the TIS, its development is also dependent on the interactions and cooperation between the actors. These may take place at various levels: within actors' groups (for example among scientists only), among actors' groups (e.g. university-industry collaborations) or across the entire system. The interactions may also be formalised into networks or remain informal bi-, trilateral collaborations. In the following paragraphs we identify the most significant collaborations across the entire UK, Danish, Dutch and German offshore wind innovation systems: knowledge networks, lobby networks and industrial networks.

2.2.1. Knowledge networks

Two types of indicators were used to map the knowledge networks: the journal publications and the European project collaborations. In this section we also mention national collaboration projects in the field of offshore wind. These indicators, however, cannot be expected to fully reveal the extent and measurable impact of learning networks because, even if learning occurs and even if it stimulates organisational change, it is very difficult to attribute the source of knowledge to one particular activity or influence of the network. Furthermore, the indicators are only useful to map a codified (explicit) type of knowledge that is formalised into scientific publications and projects. Engineering and tacit forms of knowledge and networks around such initiatives are very difficult to map in a quantitative manner. Our conclusions on informal networks and collaborations are therefore supported by the insights from the complementary qualitative research based on stakeholders' survey.

Journal publications

Journal publications as archived in the Web of Science from Thomson Scientific in the form of the *Science Citation Index* were used in subsection 1.1.2 of this report to identify the main national knowledge institutes. In this section they are used as a source of information on the knowledge institutes' R&D collaborations.

University-industry collaborations on journal publications are sparse and predominantly take place over short distances, with most co-authorship within the country

Scientific collaborations within the offshore wind innovation system, as indicated by co-authored publications, remain relatively sparse[19] in all four countries. Our data indicate that the average number of authors per publication is 1.84; the share of co-authored publications is 46% while the share of internationally co-authored papers is 17%. Furthermore, in as far as collaborations in codified knowledge production exist; a strong geographical bias is visible. Collaborations predominantly take place over short distances, with most co-authorship within the country. Co-author networks also suggest that university-industry collaborations are almost exclusively taking place within Europe and are relatively rare.

Industry does not publish in fear of their strategic knowledge being disseminated into the wrong hands

On the other hand, however, our qualitative research reveals that in Denmark the informal university-industry networks are quite tight. DTU (Risø) has particularly good connection with industry through a number of DTU (Risø) start ups; Dong Energy collaborates with the Department of Energy Technology at Aalborg University; Vestas sponsors PhDs at Aalborg University while Vestas, Siemens and LM have offices at DTU(Risø) and in Aalborg (Jacobsson and Kaltrop, 2012). In the Netherlands TU Delft closely cooperates with the Dutch subsidiary of Siemens in The Hague, Darwind, van Oord, Ballast Nedam and Boskalis (Ad van Wijk, 2012). The range of topics is wide and encompasses such issues as aerodynamics, development of wind turbines, construction, and grid development. Also German universities are involved in a number of measuring and verification programmes for and in close collaboration with the industry. The university in Hannover, for instance, had been a world leader in their research into grouted solutions for monopile foundations, long before the problems with grout connections surfaced in 2010. The German Fachhochschule in Saarbrücken has under the leadership of Prof. Friedrich Klinger developed the Vensys 62, Vensys 70/77, and Vensys 90/100 turbine models and many other complete turbine designs. Goldwind now owns 70% of Vensys and was in 2011 the world's second largest wind turbine supplier in the world, a success that can, to a large extent, be contributed to

The informal industry-university networks in Denmark, the Netherlands and Germany are tight

[19] Sparse compared to other fields such as biotechnology (Heimeriks and Leydesdorff, 2012).

the innovative direct drive technology initially developed by Prof. Klinger and his Wind Group (Eize de Vries, 2012).

Since these informal collaborations do not leave traces in the form of co-authorships of scientific publications, but do provide a strong driver for the offshore wind system development; we tend to conclude that the codified knowledge development on offshore wind (although very visible in the form of scientific publications), it is only partly relevant with regard to progress in offshore wind technologies.

European research projects

CORDIS, the Community Research and Development Information Service for Science, Research and Development, is the official source of information on the EU framework programmes. It offers interactive web facilities that link together researchers, policymakers, managers and key players in the field of research. These data permit a detailed assessment of the collaborations among organisations within the fields under study and their growth over time.

Figure 10 presents a European collaboration network of organisations aggregated on country level. Its form emphasises the centrality of the different nodes/actors in the network and shows that the UK, Denmark, the Netherlands and Germany are clear leading collaborators in the field in Europe (the four largest circles in the figure). Figure 11 further specifies organisations that collaborate mostly on European projects (Risø, ECN, TU Delft, Aalborg University, Vestas, University Oldenburg, University Edinburgh). The project collaborations show, in addition to the main organizations involved in journal publications, also a large number of companies and research organizations that do not publish but do collaborate in projects (Vestas, Dong, Lloyd, Garrad Hassan and Partners, etc).

University-industry collaborations on European research projects are more frequent than on journal publications

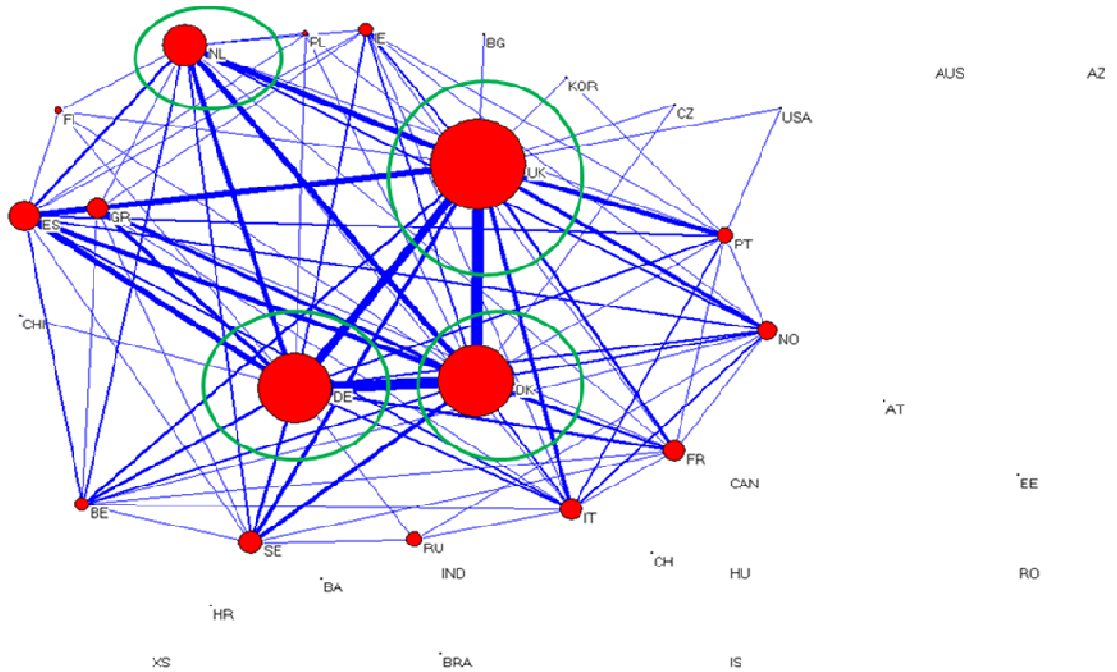

Figure 10. European collaboration network of organisations aggregated on country level. Size adjusted for occurrence in projects, lines lower than 10 removed. The four largest collaborators: the UK, Denmark, the Netherlands and Germany circled.

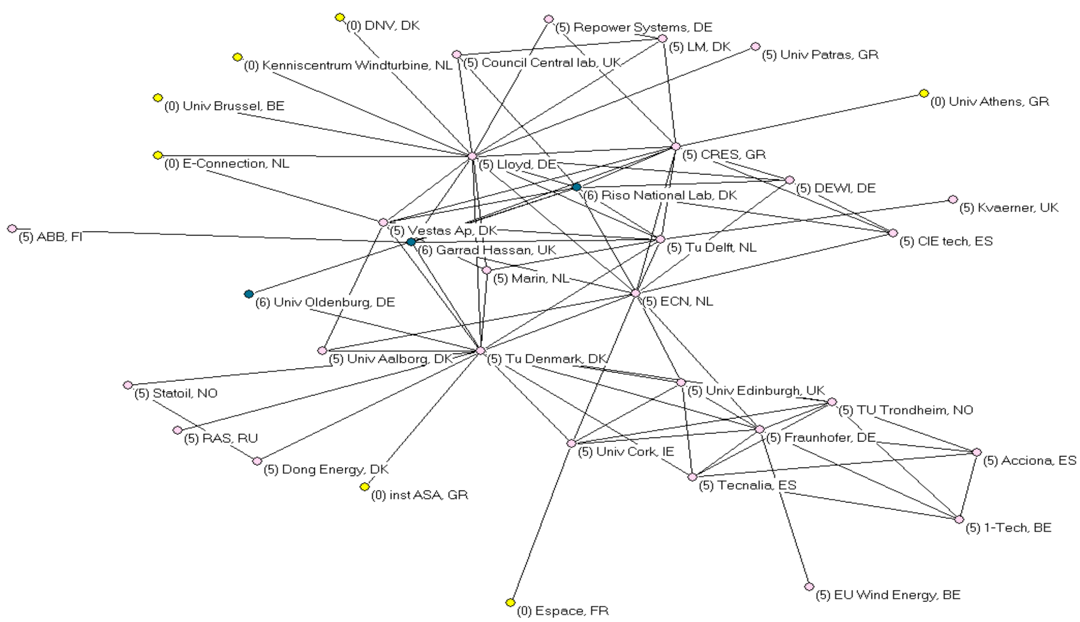

Figure 11. The core of the CORDIS collaboration network (values lower than 3 removed, unconnected nodes are not shown)

These companies are related to safety, regulations and standard issues (Germanischer Lloyd), to manufacturers of materials for wind rotors (LM Wind Power A/S) and consultancies (GL Garrard Hassan & Partners Ltd). Additionally, public research organisations from Germany (Fraunhofer), the UK (former Council for Central Laboratory of the Research Councils) and other European countries play a prominent role in European research collaborations.

Except for networks built around European projects and collaborations on scientific papers there is also a number of national and regional research networks in the four analysed countries such as the UK Carbon Trust's Offshore Wind Accelerator (OWA, 2012)[20] or Renewables Innovation Network[21], the Dutch Far and Large Offshore Wind (FLOW) project (FLOW, 2012[22]) or the German Centre for Wind Energy Research Forwind (Forwind, 2012[23]).

2.2.2. Lobby (political) networks

An important offshore wind lobby network in Europe is the European Wind Energy Association (EWEA)[24]. It actively promotes the utilisation of wind power in Europe, on land and offshore. It now has over 700 members from almost 60 countries including: developers of wind farms, owners of wind turbines, manufacturers, constructors, research institutes, utilities, consultants and O&M service providers. EWEA is thus also an industrial network and includes a number of national wind or renewable associations, such as the British Wind Energy Association (BWEA now called Renewable UK[25]), Danish Wind Industry Association[26], Dutch Wind Energy Association (NWEA[27]), and German Wind Energy Association (BWE[28]).

There are a number of European and national political networks that lobby for offshore wind

In Denmark Megawind is a partnership for mega wind turbines, established in autumn 2006 as part of the Danish government's action plan to promote eco-efficient technology. The overall aim of Megawind is to develop a new shared strategy for research and innovation in wind power in order to strengthen Denmark's position as a world leading competence centre in wind power. Megawind promotes and initiates a strengthened testing, demonstration and research strategy for wind power, and its recommendations are a reference for future strategic research in wind power in Denmark. Megawind's partners comprise: Vestas, Siemens, DONG Energy, the Technical University of Denmark, Risø National Laboratory, Aalborg University, Balluff ApS, Energinet.dk, and the Danish Energy Authority.

In Germany an important political network is the Foundation Offshore Wind Energy[29], initiated and moderated by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and supported by the establishment of the coastal countries and the industries that engage in offshore wind energy. It brings together a great variety of

[20] http://www.carbontrust.com/our-clients/o/offshore-wind-accelerator accessed 27 Apr 2012.
[21] http://www.renewables-innovation.co.uk accessed 2 Feb 2012.
[22] http://flow-offshore.nl/images/2011-08/flow_samenvatting.pdf accessed 2 Feb 2012.
[23] www.forwind.de accessed 2 Feb 2012.
[24] http://www.ewea.org accessed 2 Feb 2012.
[25] http://www.bwea.com accessed 27 Apr 2012.
[26] http://www.windpower.org accessed 2 Feb 2012.
[27] http://www.nwea.nl/ accessed 27 Apr 2012.
[28] http://www.wind-energie.de/ accessed 2 Feb 2012.
[29] http://www.offshore-stiftung.com accessed 2 Feb 2012.

actors with a broad offshore wind knowledge base. Its mission is to strengthen the role of offshore wind energy in the energy mix in Germany and in Europe and promote their development in the interests of environmental and climate protection.

At the European level there is also the European Network of Transmission System Operators for Electricity (ENTSO-E). The network is an association of Europe's transmission system operators (TSOs) for electricity. It is a successor of ETSO, the association of European transmission system operators, founded in 1999 in response to the emergence of the internal electricity market within the European Union. It contains 42 TSOs from 34 countries, which now share an interconnected transmission grid in the EU. All TSOs from Denmark, the UK, Germany and the Netherlands are part of this network. The ENTSO-E is not purely devoted to offshore wind, but it is also of great relevance for future offshore wind system expansion, which to a large extent depends on the upgrading of the electricity grid.

2.2.3. Industrial networks

There are strong national and European industrial networks. EWEA with its national associations in the UK, Denmark, the Netherlands and Germany, is the first to name. Denmark further hosts Offshore Centre Denmark which is a technical business support organisation[30]. The German Wind Energy Agency (WAB[31]) is the network of the wind energy industry in Germany‘s northwest region and serves as a nationwide contact for the offshore wind industry. Since 2002, more than 300 companies and institutes have become members of WAB; they cover all areas of the wind energy industry, from research and production to installation and maintenance.

A Europe-wide industrial network is the European Technology Platform for Wind Energy (TPWind). It is a forum for the crystallisation of policy and technology research and development pathways for the wind energy sector, as well as an opportunity for informal collaboration among Member States, including those less developed in terms of wind energy. TPWind facilitates the development of effective, complementary national and EU policy to build markets, as well as a collaborative strategy for technology development. Its ultimate aim is to achieve cost reductions to ensure the full competitiveness of wind power, both onshore and offshore. TPWind is composed of stakeholders from industry, government, civil society, R&D organisations, finance organisations and the wider power sector, at both member state and EU level. One of the main deliverables of the Platform so far, is the European Wind Initiative (EWI), a long-term, large-scale programme for improving and increasing funding to EU wind energy R&D. The EWI, which is rooted in the EU Strategic Energy Technology Plan (SET-Plan) was published by the European Commission in 2009 and is now being implemented by EU Institutions, member states and TPWind [32].

There are a few strong industrial networks in Europe and at national levels

[30] http://www.offshorecenter.dk accessed 2 Feb 2012.
[31] http://www.wab.net/index.php?&lang=de accessed 2 Feb 2012.
[32] http://www.windplatform.eu/ accessed 2 Feb 2012.

2.3. Institutions

Institutions encompass a set of common habits, routines, expectations and shared concepts used by humans in repetitive situations (soft institutions) organised by rules, norms and strategies (hard institutions). Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity and are different from organisations (such as companies, universities, state bodies, etc.). Their presence and ability to function well is necessary for a good performance of every innovation system. In the following paragraphs we outline the institutions applicable to the offshore wind TIS in the UK, Denmark, the Netherlands and Germany.

2.3.1. Renewable energy target

The following Table 5 presents an overview of national renewable energy targets per country.

Table 5 Renewable energy targets per country

Country	2020 Renewable energy target (Dir. 2009/28/EC)	2020 National renewable electricity target	2020 Projected wind offshore capacity acc. to NREAP	2020 Projected share of offshore wind in total renew. electricity
Netherlands	14%	35% (under consid.)	5.2 GW*	38%
UK	15%	30%	13 GW	38%
Germany**	18%	30%	10 GW	14%
Denmark	30%		1.3 GW	26%
EU27	20%		44 GW	

*The 5.2 GW offshore wind capacity in the Dutch NREAP will most likely not be realized since the current government moved its focus from relatively expensive electricity options such as offshore wind to less expensive renewable options (at least per kWh of final energy produced) such as biogas and geothermal heat.
**In its national renewable energy action plan (NREAP), the German government is expecting to achieve a share of 19.6% renewable energy in total energy consumption. The overachievement of 1.6% is an expectation based on current developments but is not considered a national target. Germany's federal goal (EEG, 2009) is to achieve 30% of its electric power generation from renewable energy sources by 2020. According to the German NREAP renewable electricity as the percentage of total electricity production grows from 10.2% in 2005 to 38.6% in 2020.

2.3.2. Financial incentives offshore wind farms

There is a great diversity in financial incentives and policy instruments applied in various countries (see Table 6).

Table 6. Offshore wind policy instruments in the four analysed countries

Country	Main policy instrument	Other financial incentives	Current support [€/MWh] KPMG (2010)
Netherlands	Feed-in premium	Fiscal investment deduction scheme	Tender outcome
UK	Renewable Obligation Certificate(ROC)		122.2 €/MWh certificate price for 2ROCs 57.9 €/MWh market price for electricity incl. LEC=180.1 €/MWh
Germany	Feed-in tariff	Soft loans via KfW (government-owned	35€/MWh basic tariff 130 €/MWh initial tariff

		development bank) funding programmes	20 €/MWh sprinter bonus (start up until 1 Jan 2016)
Denmark	Feed-in tariff		Tender outcome

The amount of compensation in the German feed-in tariff follows the principle of cost-covering compensation and is based on the specific electricity production costs. The plant operator receives the feed-in tariff from the grid operator. Compensation payments are distributed equally to all operators and passed on to the electricity consumers (i.e. the feed-in tariff is not paid from the state budget). The feed-in tariff is granted for 20 years and there is no annual cap.

There are big differences in renewable energy targets, regulations and financial incentives among the European countries. The process of institutional alignment is under way but incomplete

The UK has a Renewable Obligation Scheme. It was originally designed to give a single level of incentive for all renewable electricity. This strategy was changed in 2008 after it emerged that technologies such as offshore wind could not be implemented in sufficiently large volumes. From then onwards, different technologies were given different incentives within the scheme. The Renewable Obligation works through electricity suppliers needing to possess a certain amount of Renewable Obligation Certificates (ROCs) in order to avoid having to pay out *buy out* penalties in case of underachievement. The penalties are recycled to the holders of the ROCs, providing an additional incentive to invest in renewable energy.

The Dutch SDE subsidy implies that offshore wind has to compete with lower cost renewable energy technologies

The Dutch feed-in premium (Stimuleringsregeling Duurzame Energie +, SDE+) is the follow up regulation of the SDE. The SDE subsidy is either granted based on the *first come, first served* principle, or based on (cost-effective) ranking. The latter is also referred to as tender procedure. The difference between SDE and SDE+, is that in the SDE+ all renewable energy technologies need to compete for one (limited) budget, whereas in the SDE each technology has got its own (limited) budget. This implies that in the new situation offshore wind has to compete with lower cost renewable energy technologies.
The most important incentive to promote offshore wind in Denmark is a fixed feed-in tariff available for wind farms

2.3.3. Infrastructure policies

In general, there is a lack of regulatory framework on electricity trade and coordination of grid development across Europe.

Grid connection and grid integration of offshore wind is topical in Germany. The recent amendment of the German feed-in law was adopted in January 2012. This amendment particularly focuses on the greater system integration of renewable energies. Grid connection requirements, grid reconstruction and development as well as the development of storage technologies are considered to be important.

In the UK, the Department of Energy and Climate Change (DECC) has developed a regulatory regime for offshore transmission networks. A key feature of this regime is that each new tranche of transmission assets required by offshore generators will be awarded through a competitive tender process. Scotland has its own Scottish National Renewables Infrastructure Plan, assessing the suitability of Scotland's port and harbours facilities to support offshore renewables.

There is a lack of regulatory framework on electricity trade and grid development across Europe, but some countries such as Germany and UK and the EU as a whole have begun to take steps towards harmonised grid integration measures.

In the Netherlands, institutional aspects of grid connection are not fully regulated. The current division of tasks with regards to offshore wind dispatching to the grid is very unclear. Similarly, the transmission connection is not regulated by law. Contrary to Denmark and Germany where the national Transmission System Operator (TSO) is responsible for connecting farms to the grid, in the Netherlands TSO's are not obliged to connect to the grid. It is up to the project developers and companies to arrange and pay for the connection, and this lack of regulatory framework is expected to drive up grid connection costs for all developers involved.

Regarding possible locations for offshore wind farms, the UK, Denmark and Germany explicitly designate preferred areas, not the case in the Netherlands.. Here, several areas reserved for other uses are excluded (e.g. excavation, shipping routes, habitat or birds). Denmark and the UK carry out strategic environmental assessments for the designated areas. In Denmark, all licences are granted by the Danish Energy Agency, which serves as a 'One-stop-shop' for the project developer.

2.3.4. Expectations and social acceptance

Social acceptance of offshore wind is good but the technology has to compete with other renewables esp. in the eyes of politicians

The 20/20/20 climate targets of EU (EU, 2008) as well as the nationally expressed objectives in the National Renewable Energy Action Plans (NREAPs) provide a general context for growing expectations that offshore wind is potentially a huge market. Particularly in Germany the decision of the government to phase out nuclear and include offshore wind as a central element in the future energy system, fuels the hopes of big returns to investments in the offshore wind farms. The UK with great wind potential and growing market also has growing expectations on its role in the European renewable energy production. On the other hand grid issues, high price levels, non-aligned policy targets among the European countries, diverse instruments and diverging national regulatory frameworks weaken these expectations. That particularly refers to uncertainties about funding of the grid connection and overall lack of alignment of the vision on grid improvements. When it comes to alternative energy sources and ways to reduce CO_2 emissions in the context of meeting the climate goals, offshore wind is just one of the options. Therefore is has to face competition from other renewables, nuclear energy, CCS and energy savings in gathering attention and financial resources.

The social acceptance of offshore wind energy is generally more favourable than onshore. The main reasons are the distance to shore and the very small impact of construction on the residential communities.

2.4. Infrastructure

2.4.1. Knowledge infrastructure

In this section we map the level of codified and tacit (technological) knowledge development. We refer to both types of knowledge as knowledge infrastructure and we use two types of indicators to analyse it: patents and journal publications. We complement our conclusions on knowledge infrastructure with insights from qualitative research based on actors' interviews.

Patents

Patent classifications can provide a good overview of the different classes of technologies (and their trajectories) that are relevant for the analysed TIS. We rely, particularly, on patent data to study the development and stock of *codified* (technological) knowledge that has potential commercial applications. The European Patent Organisation (EPO) database offers free access to more than 70 million patent documents worldwide, containing information about inventions and technical developments from 1836 to date. To study the knowledge infrastructure in offshore wind, patents are selected by the keywords *offshore wind*. The following, Table 7, presents an overview of the most important patent classes in offshore wind. The large majority of these patents were filed after 2002.

Vestas and Siemens are in the top worldwide companies patenting in the field of wind turbines and vessels

Table 7. Most important patent classes relevant to offshore wind

Patent code	Description
F03D	Wind motors
B63B	Ships or other waterborne vessels; equipment for shipping
B01D	Separation
H02K	Dynamo electric machines
F03B	Machine or engines for liquids
E21B	Earth or rock drilling
E02B	Hydraulic engineering
F16L	Pipes; joints or fittings for pipes
B29C	Shaping or joining of plastics

Most patents are classified in the area F03D (wind motors). The second most prominent set of technological invention can be classified as B63B (ships or other waterborne vessels, equipment for shipping). In the patent class F03D, the main companies involved in manufacturing wind turbines according to the EPO patent analysis are General Electric with 453 patents, Vestas with 344 patents and Siemens with 193 patents. The UK and Dutch organisations are not dominant players in this respect and no significant patenting activity comes from universities in any of the four countries under study.

Journal publications

Journal publications are the second indicator of scientific *codified* knowledge development. The screening of journal publications allows not only for the identification of knowledge institutes (as in section 2.1.2 – knowledge institutes), but it also helps to trace the involvement of other types of actors as co-authors of scientific articles, such as industry or consultancies. Our analysis reveals two broad trends in this respect.

Codified knowledge production on offshore wind takes place in public research organisations and is not directly connected to industry

Firstly, the number of countries publishing on offshore wind energy, as well as the number of publications in the field, shows a steady increase in recent years (see Figure 12). Before 1994 hardly any publications dealt with offshore wind energy, while now around 350 papers are published yearly. Also, the number of (scientific) journals involved in offshore wind energy is expanding rapidly from 23 in 1994 to 346 in 2010.

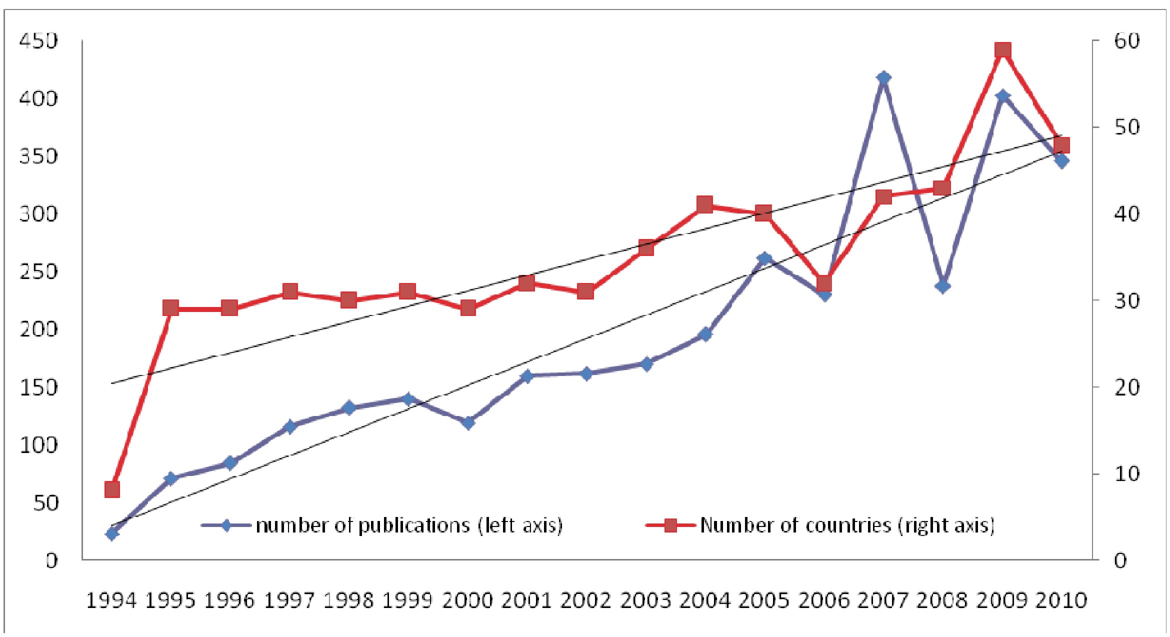

Figure 12. Worldwide growth of publications and countries involved in the codified knowledge production on offshore wind, during the period 1994-2010

Secondly, we observe and we showed earlier (in section 2.1.2 - knowledge institutes, Table 2), that scientific codified knowledge production on offshore wind actually takes place in public research organisations. It is not immediately connected to industry as judged by the very few companies involved in journal publications. The screening of the most important keywords used in the UK, Danish, German and Dutch publications confirms this divergence: there is a great deal of scientific information produced on wind forecasts, oceans, climatic conditions and how to fit the technology into specific geographical conditions, rather than on technology itself (see figure 13). Also our interviewees emphasised, that at events like EWEA 2012 there is a rather distinct separation between *science and research* and *resource assessment*, and other categories like 'hardware technology' (Eize de Vries, 2012).

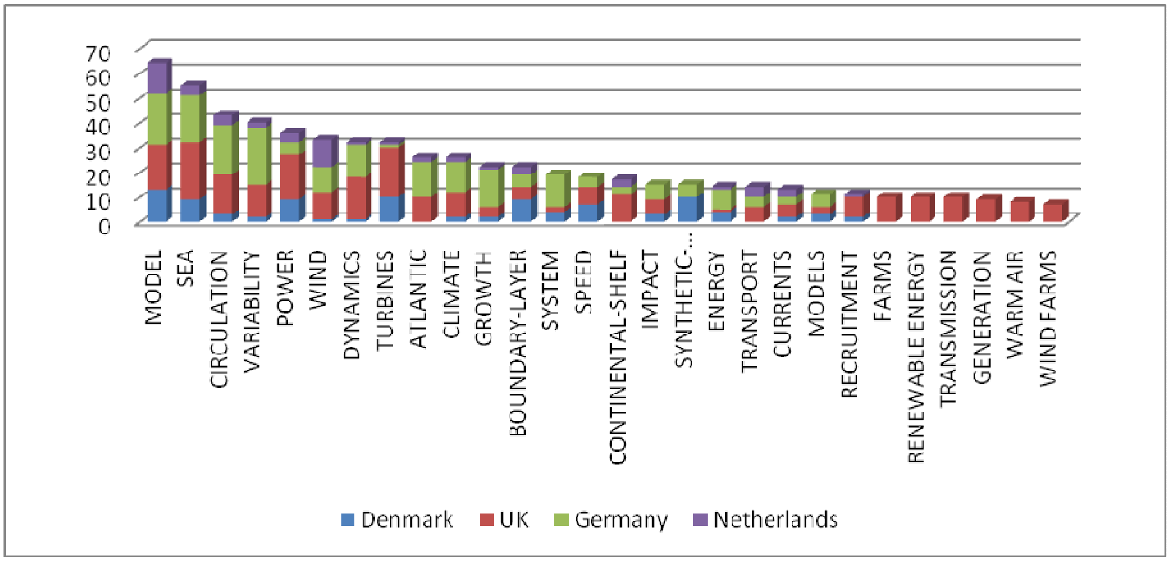

Figure 13. The most important keywords in the UK, Danish, Dutch and German offshore wind publications[33]

As far as the analysis of patents and journal publications is useful for the mapping of who is involved in codified knowledge production, to what extent and in which areas, these two indicators cannot be used to judge the relevance and impact of the knowledge produced. From our qualitative research based on interviewing various offshore wind actors we know that tacit, engineering knowledge is produced by companies. For example, many German firms are world leaders with regard to dedicated R&D, ground-breaking wind turbine and other wind technology development, and the implementing of advanced offshore wind technology. Germany was the first country in the world to install an offshore 4.5 MW turbine in 2002: the Enercon E-112. Enercon later decided not to enter the offshore market. Another two offshore dedicated wind turbines were installed in 2004: the REpower 5M and Multibrid M5000. In 2005 Aerodyn Energiesysteme developed a third 5 MW turbine for BARD within a record nine-month period, of which two prototypes were installed in 2007. Also innovative foundations were developed by REpower and Weserwind (jacket), and BARD (tripile) (Eize de Vries, 2012). Because of the tacit character of this knowledge, and for reasons of not losing their competitive advantage, companies do not codify and do not eagerly share this knowledge, which makes its analysis very difficult.

Technological opportunities in offshore wind are not fully dependent on major scientific work at universities

Based on these findings we conclude that innovations in offshore wind are incremental, with in-house R&D on core technologies in Siemens and Vestas. While public research provides insight into a wide range of topics for

[33] Figure 13 further suggests some specialization patterns among the four analysed countries. For example, 'turbines' is popular in the UK and Denmark but not in the Netherlands or Germany. The UK has a large number of contributions that are not covered by other countries such as 'renewable energy' or 'wind farms'.

further incremental development, real opportunities to innovate in offshore wind may rather come from other applied and more fundamental technological advancements in non-codified knowledge, equipment, infrastructures and instrumentation. Possibly, non-codified sources of knowledge in terms of suppliers or users may play a crucial role.

2.4.2. Physical infrastructure

The presence and sufficient capacity of the physical infrastructure is very important for the development and functioning of every innovation system. Its lack or malfunction may have serious consequences for the functioning of the TIS. In this subsection we identify and analyse the UK, Danish, Dutch and German offshore wind infrastructure: wind turbines, wind farms, cables, vessels, foundations, grid and harbours.

Wind turbines

As much as wind turbine technology is well developed for onshore applications, offshore wind technology is still a young industry and seen by many companies as risky. For a number of years there was a shortage of control systems for wind turbines, and of other key components such as gearboxes and transformers. Also strong demand for cheaper and 'less risky' onshore projects made manufacturers stay away from offshore wind power (EWEA, 2011a). Today, experienced suppliers, Vestas, Siemens and REpower, as well as BARD and Areva Wind, successfully operate a more mature series of wind turbine models up to 6.15 MW offshore, with new installations up to 7 MW+ in development. There is also a growing range of offshore market newcomers (see section 2.1.4 – industrial actors) who developed, or are developing, new wind turbines of around 5 – 8 MW, characterised by a wide choice in different drive systems and other dedicated design solutions. AMSC is an example of a new entrant that is developing a 10 MW turbine with a high temperature superconductor (HTS) generator; meanwhile a UK company is planning an unusual 10 MW vertical axis turbine called Aerogenerator X. Even though several of the first-generation 3.6 – 5 MW turbines were already offshore-dedicated designs, second and third-generation turbines will increasingly benefit from experience and fresh know-how for further adaptation to harsh offshore conditions (Eize de Vries, 2012). EWEA (2011a) expects 4-12 new wind turbine models to reach some level of market readiness in the next decade, with overall supply meeting and even exceeding the demand in Europe, with potential for export.

There are large technical challenges for the design of turbines and tests are underway with 4-12 new turbines expected to enter the market later this decade, still further R&D is needed to make the technology cost-effective

Wind farms

The Table 8 presents a list of the top offshore wind farms that are currently operational, rated by capacity.

Table 8. Top operational offshore wind farms in the world, according to capacity (source: JRC, 2012)

Wind farm	Capacity (MW)	Country	Manufacturer	No.	Turbine model	Year
Greater Gabbard	382*	UK	Siemens	106	SWT-3.6-107	2011
Walney I & II	367	UK	Siemens	102	SWT-3.6-107	2012
Thanet	300	UK	Vestas	100	V90-3.0 MW	2010
Horns Rev 2	209	DK	Siemens	91	SWT-2.3-93	2009
Rodsand II	207	DK	Siemens	90	SWT-2.3-93	2010
Chenjiagang Xiangshui Intertidal	201	CN	Dongfang	134	FD77-1500	2010
Robin Rigg	180	UK	Vestas	60	V90-3.0 MW	2010
Gunfleet Sand	173	UK	Siemens	48	SWT-3.6-107	2010
Rodsand 1 - Nysted	166	DK	Siemens	72	SWT-2.3-93	2003
Belwind (Bligh Bank)	165	BE	Vestas	55	V90-3.0 MW	2010
Horns Rev 1	160	DK	Vestas	80	V80-2.0 MW	2002
Ormonde	152	UK	REpower	30	REpower 5M	2011
Princess Amalia (Q7)	120	NL	Vestas	60	V80-2.0 MW	2008
Lillgrund	110	SE	Siemens	48	SWT-2.3-93	2007
Egmond aan Zee (OWEZ)	108	NL	Vestas	36	V90-3.0 MW	2006
Dong Hai Bridge 1	102	CN	Sinovel	34	SL3000/90	2010
Jiangsu Rudong Offshore/ Intertidal Demonstration	99	CN	Sinovel & Siemens	38	SL3000 & SWT-2.3-101	2011
Inner Dowsing	97	UK	Siemens	27	SWT-3.6-107	2009
Lynn	97	UK	Siemens	27	SWT-3.6-107	2009

* Of a total of 504 MW (140 turbines), 106 turbines (382 MW had produced power by 31.12.2011, but the construction continues (Roberto Lacal-Arantegui, 2012).

In addition to wind farms already in operation a number of new ones are either planned or consented. The installed capacity in EU in 2011 was 3.8 GW, out of which the UK accounted for 55% (2.1 GW), Denmark 23% (0.9 GW), Germany 5% (0.2 GW) and the Netherlands 6% (0.2 GW). Nine offshore projects were under construction in 2011 with the total capacity of 2.3 GW. Furthermore, preparatory work started in 2011 on nine other projects of which seven are in Germany (2.3 GW) and two in the UK (0.6 GW). A further 18 GW has been consented of which 5% is in the UK, 12% in the Netherlands, 45% in Germany and none in Denmark. In the case of the Netherlands, it must be noted that only part of the consented capacity has been granted subsidy for the operation; the ones without subsidy will most likely not be realized. The following figure (Figure 14) shows the installed, consented and planned capacity per country in 2011.

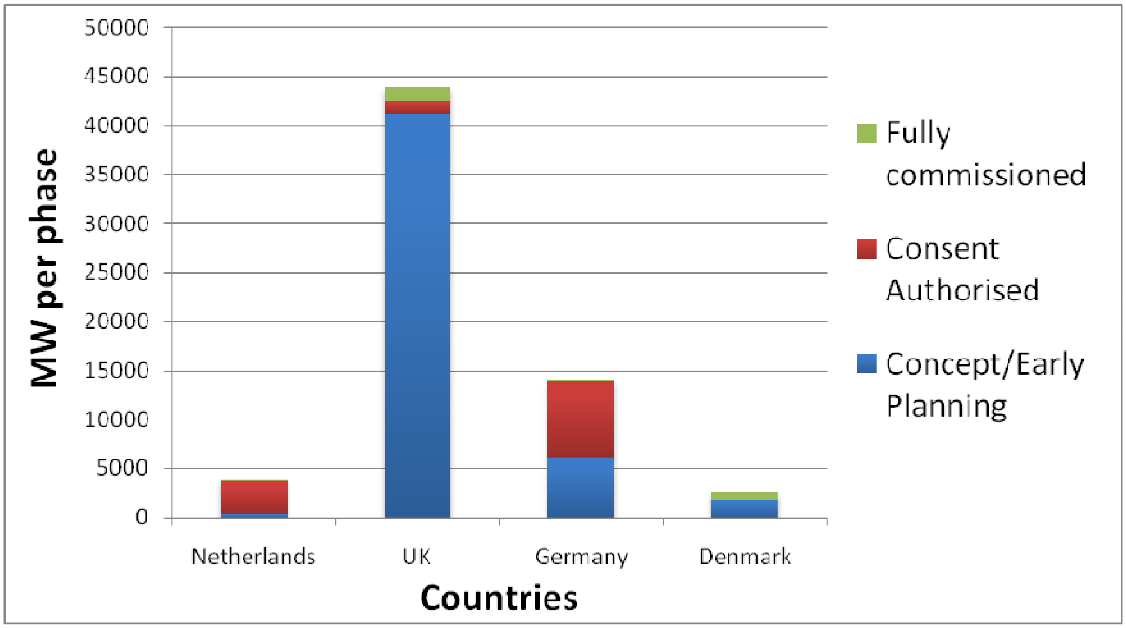

Figure 14. The amount of MW in different development stages per country in 2011

EWEA (2011d) having analysed all planned wind farms concluded that, in general, sites for new wind farms are bigger in number and power-rating, and moving further from shore into deep water, posing additional logistical and technological challenges. There is also a tendency to connect wind farms with each other into hubs, and then to the grid, rather than connecting separate wind farms to the grid for economic and time reasons.

Cables

For an offshore wind farm to operate to its fullest efficiency/capacity, different types of cables are necessary. These are specific subsea cables: export cables and inter-array cables. Both types are high voltage cables (in either AC or DC electrical power transmission applications). As we showed earlier (section 2.1.4 Industrial actors) there is a limited range of suppliers for high-voltage (HV) subsea cables due to high investment costs and long lead times for bringing new cable capacity online (3 years). Also the demand for this type of cable begins slowly to outpace the manufacturing capacity. If the offshore wind sector continues to expand at the current rate, availability of cables may become a serious constraint (EWEA, 2011a).

If the offshore wind sector expands to meet the target, availability of cables may become a serious constraint

Foundations (substructures)

Substructure supply and installation for offshore wind farms represent about 20-30% of capital costs. There are also (perceived) low technical barriers for entry, which together present major opportunities for national manufacturing in the offshore wind countries of Europe, but past experiences have not been uniformly positive. EWEA (2011a) argues that it is, therefore, not necessary for a country to be manufacturing turbines in order to develop a strong offshore wind industry.

There are different types of foundations, depending on the water depth, seabed and turbine characteristics, but most common are: monopile, gravity based structure (GBS) and steel three-dimensional structures (jackets, tripods, tripiles). Most of the operating wind farms in Europe do not exceed 25 m water depth and therefore use monopiles. GBS has been applied in several more shallow-water wind farms and in the first phase of Thornton Bank (6 x 5 MW) (Eize de Vries, 2012). Also countries such as the UK and the Netherlands own many sites that offer geographically favourable conditions for the use of monopiles, their use however depends on the wind turbine size and power rating. Germany's deep-water North Sea sites are generally not suitable for the use of monopiles; its potential new sites are at a greater distance to shore and at greater depth (KPMG, 2010). In the case of wind farms being placed further from shore into deeper water, different types of floating structures could become feasible, but they are currently not being produced by any of the analysed countries.

Availability of substructures and vessels is good in Europe but requires constant

Vessels

Currently 6 different types of vessels are necessary to install and operate a wind farm. Vessels are needed, for example, to transport components and personnel, to install the substructure, turbines and substations as well as to lay cables. EWEA (2011a) expects that 'until 2020 the demand for vessels will grow to around 27 per site. Jack-up vessels remain the industry workhorses as vessel specialisation increases. The industry is seeing increased specialisation of vessels for offshore wind generally, and for the specific tasks performed on an offshore wind site. Nevertheless, jack-up designs are expected to continue dominating vital installation procedures and particularly turbine installation. Developers are looking at strategic investments to secure vessels. However, in the near term, supply constraints are decreasing, which may stem this trend. The vessel supply chain outlook is strong through to 2015 with several new-builds, increased levels of competition, and supply likely to meet demand. Through the latter half of the decade increasing pressure may return if further investments are not made'.

Harbours

Many of the Dutch, Danish, German and UK harbours are particularly suitable for large logistical offshore wind operations. Still adjustments are necessary

Harbours are of vital importance to the offshore wind industry but they need to be specifically adapted (deep water quays, large storage facilitates, space for manoeuvre) to be able to serve the offshore wind industry. Two types of ports are important for offshore wind. First type includes manufacturing ports where the manufacturing facility is located close to, or at the port, and ready components/assemblies are exported directly to the offshore site. The second type are mobilisation ports where the components and turbines are received ready and transported to either the installation vessels directly or the feeder vessels which take them on the offshore site (EWEA, 2011a).

Many of the UK, Danish, Dutch and German harbours have direct access to the North Sea and the Baltic Sea. They also retain significant experience and infrastructure developed for operating the offshore gas and oil industry. This makes them particularly suitable for large logistical operations related to the installation of wind farms.

Examples of such harbours in the four analysed countries are presented in Table 9 and are marked as having 'offshore wind experience'. The remaining harbours are 'potential sites only'.

Table 9. The current harbour infrastructure in the four analysed countries (based on EWEA, 2011a selection)

Country	Harbour	Remarks
Netherlands	Eemshaven	Offshore wind experience
	IJmuiden	Offshore wind experience
	Vlissingen	Offshore wind experience
	Den Helder	Potential only
UK	Barrow	Offshore wind experience
	Cape Firth	Potential only
	Dundee	Potential only
	Great Yarmouth	Offshore wind experience
	Hartlepool and tees	Offshore wind experience
	Humber	Offshore wind experience
	Hunterstone	Potential only
	Medway	Potential only
	Methil	Offshore wind experience
	Milford H	Potential only
	Montrose	Potential only
	Mostyn	Offshore wind experience
	Newheaven	Potential only
	Peterhead	Potential only
	Portland	Potential only
	Ramsgate	Offshore wind experience
	Southampton	Potential only
	Swansea	Potential only
	Tyneside	Potential only
Germany	Bremerhaven	Offshore wind experience
	Cuxhaven	Offshore wind experience
	Emden	Offshore wind experience
	Lubmin	Offshore wind experience
	Rostock	Offshore wind experience
	Sassnitz	Offshore wind experience
	Wismar	Potential only
Denmark	Aalborg	Offshore wind experience
	Aarhus	Offshore wind experience
	Copenhagen	Potential only
	Esbjerg	Offshore wind experience
	Frederikshaven	Offshore wind experience
	Nyborg	Offshore wind experience

For example, Esbjerg (DK) is considered by one of the leading energy business analysts in the world, Douglas-Westwood, as a European leader when it comes to the supply chain for offshore energy. The municipality of Esbjerg, with investments of billions of kroner in roads, railroads, land used for business purposes, education and research, plans to take advantage of the huge growth potential in offshore energy and bioenergy systems[34].

[34] http://www.esbjergkommune.dk/en-gb/work/energymetropolis.aspx accessed 30 Dec 2011.

The Dutch Eemshaven is also strategically located right below the German continental shelf and already serves as a logistical and supply harbour for many offshore wind projects (Bard 1, Alpha Ventus). Since many new wind turbines are to be built in the North Sea in the years to come, Eemshaven is expected to develop into the logistics hub of the Netherlands' offshore wind industry. To meet the requirements of an offshore wind facility, Groningen Seaports is investing about €25m in 700 metres of new heavy-duty quay facilities at Eemshaven and an extension of Beatrixhaven by 500 metres. The work is scheduled for completion in 2013[35].

There is an emergence of strong offshore wind clusters around many European offshore harbours

The UK has the greatest potential wind energy resource out of all the analysed countries (EEA, 2009), i.e. an extensive coastline, and thus good conditions for offshore wind farm development. However out of the many UK harbours mentioned in the Table 9 only a few have offshore wind experience: Barrow, Yarmouth, Humber, Methil, Mostyn and Ramsgate. To support the establishment of offshore wind manufacturing at port sites in the UK, the government has made up to £60m available (Department of Energy and Climate Change, 2011)[36]. The Crown Estate also announced it would work with interested ports and manufacturers to realise the potential of their sites.

In Germany, to meet the offshore wind challenges, there is a drive towards cluster building for offshore wind manufacturing in closely located ports (e.g. German cluster Bremenhaven, Cuxhaven, Emden). These initiatives are the result of the cooperation between public and private sectors (EWEA, 2011a).

In general, offshore wind energy offers a significant opportunity for harbours to offset the downturn hitting traditional activities. These harbours, however, still need to develop a capacity dedicated to accommodating the establishment of coastal manufacturing and assembly facilitates, as well as, to avoid transport constraints (roads, trucks) related to the increased size of wind turbines (EWEA, 2011a).

Grid

Europe's electricity grids were originally built to handle large centralized (fossil fuel) power plants, rather than great amounts of distributed renewable generation, such as that produced by offshore wind farms. The grid therefore (stability and capacity wise) is not always ready to accept rising amounts of offshore wind energy, and face the challenges related to increased electrification as more renewables come online. The electricity grid is also largely designed around national borders (Wind directions, 2012). Because there is no single market for electricity but multiple national markets, the amount of traded electricity is very low. Grid

Early initiatives are under way at national and European level to enhance the capacity and access to the grid

[35] http://www.groningen-seaports.com/Business/Offshorewindindustrie/tabid/2133/language/en-US/Default.aspx accessed 30 Dec 2011.

[36] http://www.decc.gov.uk/en/content/cms/meeting_energy/wind/offshore/business_dev/business_dev.aspx accessed 30 Dec 2011.

development is therefore not only a technical issue but also an institutional problem.

Europe's electricity grid is a sum of national grids and multiple markets. The amount of traded electricity is very low. Bigger amounts of renewable electricity are challenging for the grid

At EU level plans for grid development have already started. At the end of 2011, the European Commission has created an innovation grant of €3m towards the development of a programme to warrant European grid security in the future. Currently there are about ten projects being set up (DG-ENER, 2012). Together with a number of TSOs and universities involved, the Dutch/German national Transmission System Operator TenneT was made responsible for this project. The programme is aimed at integrating a growing share of sustainable electricity into the grid and at managing the increasing cross-border electricity flows (Tennet, 2011[37]). TenneT BV is Europe's first cross-border electricity transmission operator. A significant section of TenneT's high-voltage grid borders onto the North Sea in both the Netherlands and Germany. Two connections for offshore wind farms have already been completed in the German section of the North Sea and work is underway on three more wind farms. In addition, the Dutch electricity grid is linked to Norway by means of an undersea cable link (NorNed) and to the United Kingdom (BritNed cable). There are also plans for new undersea cables to Norway (NorNed2 and NORD.LINK) and Denmark (COBRA cable). These interconnections will play an important part in the further development and integration of wind energy and the promotion of market integration.

In the UK, the Crown Estate has initiated a dedicated Transmission Programme to play a more effective and proactive role in the delivery of the necessary offshore infrastructures. The immediate challenges the Crown Estate aims to address in this programme are: (i) sustainable use of seabed and foreshore for cable corridors to cope with intensified cable laying activities; (ii) regulatory improvement to enable offshore energy projects to secure connections in a timely, reliable and cost efficient way; (iii) development of a transmission network that will contribute to the aim of reducing cost and risks of delivering offshore renewable; also delivery of offshore transmission to avoid unnecessary consenting delays and uncoordinated development; and (iv) mitigation of a potential bottleneck in supply of offshore export power cabling. In addition, the Crown Estate is contributing to the current review and reform on transmission charging and electricity markets. To prepare for potential electricity export from renewable energy sources to Europe, post 2025, the Crown Estate plans to investigate the development of a pan-EU offshore grid to underpin future leasing rounds and renewable energy export. This will be in conjunction with the North Seas Countries' Offshore Grid Initiative confirmed by the ten North Sea countries and the EU in December 2010' (The Crown Estate, 2011)[38].

Denmark is the world leader in integrating renewable and distributed energy sources into electric power systems. The country currently has about 25% wind power penetration into the system, and their conventional generation is highly distributed with combined heat and power plants dispersed throughout the landscape. In order to achieve an even greater wind

[37] www.tennet.org, accessed 30 Dec 2011.
[38] http://www.thecrownestate.co.uk/media/211168/uk_offshore_wind_report_2011.pdf accessed 12 Apr 2012.

penetration and glean the most benefit from the distributed power system, Energinet.dk, the Danish TSO Company, who is the owner and operator of the high-voltage power system in Denmark, is working on developing an innovative grid management technology. This technology will optimise the performance of the grid by maximising the contribution from renewables and enhancing the utilization of the distributed combined heat and power plants. In addition, this technology will ensure grid stability and security with the capability to segment portions of the network into *virtual power plants*, aggregate resources to provide ancillary services, and provide the ability to more easily restore power in the event of network breakdown.[39]

At a European level a European Network of Transmission System Operators ENTSO –E was established that brings six TSO s together in order to develop a 10 year plan for the grid.

2.4.3. Financial infrastructure

Alongside the physical and knowledge infrastructure, availability of funds for installation of wind farms is a critical factor that influences the operation of the innovation systems. In the following table (Table 10) we show the overview of capital costs of fully commissioned wind farms in the UK, Denmark, the Netherlands and Germany.

Table 10. Capital costs of fully commissioned farms in the UK, Denmark, the Netherlands and Germany. Conversion rates 26 April 2012[40].

Country	Farm name	Project Cost (million EUR)
UK	Blyth	4.88
	North Hoyle	97.60
	Scroby Sands	92.16
	Kentish Flats	128.10
	Barrow	170.19
	Burbo Bank	220.82
	Lynn	366.00
	Beatrice Demonstration	42.70
	Inner Dowsing	366.00
	Robin Rigg	483.12
	Thanet	1098.00
	Gunfleet Sands I + II	512.40
	Rhyl Flats	241.56
Denmark	Vindeby	8.80
	Tunø Knob	11.95
	Middelgrunden	47.00
	Samsø	30.00
	Horns Rev 1	272.00
	Rønland	25.00
	Nysted	200.00
	Frederikshavn	1344.10
	Horns Rev 2	470.00
	Rødsand 2	400.00
	Sprogø	72.00
	Avedøre Holme	24.82
	Poseidon	n/a

[39] http://www.spirae.com/vision-reality.php accessed 12 Apr 2012.
[40] www.xe.com.

The Netherlands	Lely	5.37
	Irene Vorrink	23.88
	Prinses Amalia windpark	350.00
	Egmond aan Zee	200.00
Germany	ENOVA Offshore Project Ems Emden	n/a
	Breitling	n/a
	Alpha Ventus	250.00
	Hooksiel	n/a
	EnBW Baltic 1	200.00

Next to fully commissioned projects, there is a set of consented and planned wind farms for which the capital costs are not yet fully known. It is therefore difficult to assess this infrastructural element of the innovation systems. The qualitative research based on actors' interviews suggests that the availability of funds for capital costs is problematic and increasing number of actors (utilities and banks predominantly) need to be involved to make one project bankable.

3. Functional analysis

The structural analysis, we performed in the previous section (Section 2), gives a good overview of the innovation systems (actors, networks, institutions and infrastructure). Often, however, different innovation systems have similar components, but they function in an entirely different way. Therefore, next to analysing the structure, it is also important to assess how particular innovation systems function, in other words - what the actors do and whether this is sufficient to develop successful innovations. Analysis of these processes allows us to address the performance of an innovation system and complement the insights from the structural analysis. To appraise this performance a set of evaluation criteria is used that, in the literature, have been labelled as 'functions of innovation systems'. The 'functions' state how an innovation system performs at a specific point in time and they include: entrepreneurial activities (F1), knowledge development (F2), knowledge exchange (F3), guidance of the search (F4), market formation (F5), resources mobilization (F6) and legitimacy creation (F7).

In this section we evaluate the functioning of the UK, Danish, Dutch and German offshore wind innovation systems at the end of 2011. Since innovation does not recognise optimum it is impossible to judge whether there is *enough* of it. Our discussion on the *sufficiency* of innovative activity in the areas defined by the functions is, therefore, based on the qualitative evaluation of the capacity of the four analysed systems to grow further and accelerate, and not on quantitative assessment in the context of reaching the European and national targets. We discuss each function in all four countries to compare the various innovation systems and draw, wherever possible, general conclusions for the European offshore wind TIS. The discussion is ordered along a set of diagnostic questions that help asses each function. The section closes with a graphical overview of the functional dynamics in each country. A 5-tier scale of absent-weak-moderate-strong-excellent is used to demonstrate the strength or weakness of each function.

The functioning of the innovation systems is assessed based on information from several sources: over 30 stakeholder's interviews; 10 reviews of the draft report; events reported on in the Windpower Monthly magazine in 2011, as well as data from a number of industrial and scientific publications and web pages of offshore companies, their products and activities. During the interviews experts and stakeholders from the UK, Denmark, the Netherlands and Germany were asked to express their views on the functioning of the national TISs along with a set of diagnostic questions (see Annex 1).

3.1. Entrepreneurial experimentation (F1)

No innovation system can exist without entrepreneurs. Their role is to turn knowledge into concrete action that generates new business opportunities and value to their societies. Entrepreneurs can be new entrants seeking business opportunities or incumbent companies diversifying their activities to realise new business prospects. To evaluate the entrepreneurial experimentation in the four analysed countries we looked at the number and the type of actors involved in experimentation (incumbent vs. start ups) as well as the number and type of activities of these actors, such as involvement in national versus international projects, specialization along the value chain or focus on large scale production.

3.1.1. Are there sufficient and suitable types of actors contributing to entrepreneurial experimentation?

Our structural analysis shows (particularly section 2.1.4) that larger incumbent companies dominate the value chains of the four analysed countries (Figures 1-4). Analysis of their entrepreneurial activity (see Box 1 for selected examples) further shows that the incumbents also contribute most to the entrepreneurial activities. In the Netherlands these are established offshore construction firms who diversified their activities to offshore wind (such as Sif, Smulders, Ballast Nedam, Van Oord, etc.), in Denmark and Germany wind turbine manufacturers (Vestas and Siemens; REpower and Multibrid) are leading entrepreneurs on a European scale. In the UK large foreign multinational utility companies, such as E-on, RWE, Vattenfall and Dong Energy, dominate as owners and operators of the wind farms. Incumbents, who diversify their business portfolio, accelerate the system development, are less vulnerable to changing political winds in the country, and are more stable financially. Their presence in the analysed value chains is also beneficial for the offshore wind system at a European level. This is because they have the capacity to exercise a larger impact on the wind power lobby and, for instance, contribute to the mobilization of complementary resources for, among others, grid improvements. In the UK the dominance of utilities as owners and operators however may, according to Markard and Petersen (2010), also have some negative bearings, mainly on social acceptance of the technology applied in projects, which is partially based on the access to public finance by smaller parties. If the funds begin to be streamlined to the large utilities this may raise issues with the legitimacy of the system. Markard and Petersen (2010) also suggest that this particular ownership structure may further alter the market concentration on the demand side, as bigger companies negotiate more powerfully with equipment manufacturers.

On the other hand, despite the current visible dominance of Vestas and Siemens in wind turbine manufacturing, there is an increased number of new entrants in various countries all working on new turbine models. New entrants are critical for entrepreneurial activities and are a sign of the systems' dynamic development. Together with incumbents the new entrants create a good balance, to the extent that EWEA estimates that over the next decade the supply of wind turbines has the chance to overtake the demand (EWEA, 2011a). In the area of cables there are very few new entrants, and some in the area of installation vessels. If that trend persists it may imply that the existing cables and vessel companies will have to increase their overall research, product development and manufacturing volume efforts, in order to meet the growing demand.

3.1.2. Are the amount and type of activities of the actors sufficient?

The structural analysis as well as the analysis of the functional pattern based on Windpower Monthly reveal that there is a visible division of labour and specialisation between the countries along the value chain; hence the entrepreneurial activities of the analysed countries take place in various phases of the chain. The Dutch entrepreneurial activities are mostly in the construction phase with focus on foundations and substations, Danish in wind turbine manufacturing and construction focused on heavy vessels, while the UK in wind turbine and subsea cables installations (see also Figure 9 earlier). Germany is active in many areas ranging from design and production of wind turbines, foundations, towers, vessels and a wide range of components.

Data also suggest that wind farms are mostly owned and managed by national actors but constructed by a number of international companies. Particularly, the UK innovation system is more open to foreign actors compared to the other three. That means that even though the UK has a great number of new wind farm projects, it is the foreign industry that benefits most. At the same time, we also observe that Dutch (mainly construction) companies, due to poor domestic market conditions, are the most internationally oriented.
What does it mean for the functioning of the offshore wind innovation systems? Even though no TIS is confined to national borders, still national factors (such as access to funds, permitting procedures) significantly contribute to the success of a TIS. This explains why often TISs are analysed in the context of a specific country. From the European perspective the specialisation along the value chain is not problematic, because the four countries seem to complement each other rather well. Similarly, the limited number of the UK actors in the UK value chain is not problematic either as long as foreign companies do the job. However, when looking from the national perspective, the specialisation may suggest an underdeveloped value chain with a limited number of key actors in specific phases of the value chain. This may further result in the loss of legitimacy and political support at the national level, in case when national incentives for offshore wind primarily lead to the building up of the offshore wind industry abroad. The rather complete European offshore wind TIS may then turn out to be not sustainable.

In the situation where countries, the UK in particular, decide to protect their national markets and increase the number of domestic actors in the value chain – this would mean the loss of an important market and source of revenue for international constructors. This would specifically put very welcome and essential pressure on the Dutch government to develop a domestic market, and to avoid erosion of its own offshore wind industry that currently earns its bread abroad.

3.1.3. How does the function score?

In view of the above findings and despite the fact that interviewees judged this function relatively highly, we suggest that the function entrepreneurial activity might become problematic and hamper further development of the TIS through the interlinked issue. This is especially the case when legitimacy in the UK is reduced (as a result of money flowing abroad). This situation would then have serious impacts on entrepreneurial activity in all countries. Because of a lack of a strong home market, especially in the Netherlands and Denmark, the offshore wind industry in these countries (and the UK itself of course) would be most affected. German entrepreneurial activity (except for Siemens) would probably be less strongly affected. We therefore evaluate the function F1 entrepreneurial activities at the level of: moderate (3) in the UK, excellent (5) in Germany; and (conditionally) strong (4) in the Netherlands[41] and Denmark. It must also be emphasised that even though these are quite high scores still there are more entrepreneurial experiments needed in all four countries to reduce the risks and increase experience in the field.

Box 1. Selected examples of the UK, Danish, Dutch and German entrepreneurial activities in 2011

- Consortium of Strukton and Hollandia worked on foundation of German Dan Tysk offshore wind project (NL)
- Van Oord invested in new vessel for installing offshore wind turbines (NL)
- The Dutch foundation manufacturer Smulders reached the level of 60% of all offshore wind foundations currently constructed in the North Sea (NL);
- Royal Doeksen invested 4 million in two maintenance vessels while Abis shipping builds new vessels for transporting turbines (NL)
- Royal Haskoning, IHC Merwede, Ballast Nedam and Van Oord focused on the prospective French market. Only Smit Marine contracting resigned from investment in new vessels for cables because of uncertainty of governmental policies (NL)
- REpower started the series manufacture of its latest 6.15MW 6M model (DE)
- BARD installed two 6.5MW prototypes fitted with an innovative Winergy gearbox design (DE)
- Siemens launched a version of its 6MW offshore turbine with a 154-metre rotor, and installed the first 6MW prototype (DE)
- Siemens received a 288MW order from E-on for an offshore wind farm in the North Sea (DE)
- Siemens increased its order levels in 2011, in a year that looks likely to have been one of steady growth for many firms in the industry(DE)
- Siemens confirmed it plans to install a grid connection in the North Sea for the 864MW SylWin offshore wind farm cluster for the Dutch-German transmission grid operator TenneT (DE)
- Siemens Energy has begun work on its recently won contract to build a transmission link for a 400MW offshore wind farm in the North Sea -in a joint venture with Italian cabling firm Prysmian (DE)
- German offshore wind developer Windreich signed a deal with Areva for 42 5MW offshore wind turbines for the Deutsche Bucht offshore wind farm (DE)
- Eneco handed Vestas a 129MW supply deal for a wind project off the Dutch coast (DK)
- Vestas got a contract for a supply of wind turbines to developer PNE Wind for a 252MW offshore project in Germany (DK)
- Vestas unveiled plans for next-generation 7 MW offshore wind turbines (DK)
- Dong Energy signed a long-term framework agreement for the supply of foundations to its offshore wind farms with Danish manufacturer Bladt Industries (DK)
- Dong Energy confirmed it plans to build the 320 MW Borkum Riffgrund 1 wind farm off the German coast (DK)
- Rolls Royce supplied water jets for six new wind farm support vessels in separate orders for the UK and Australian shipbuilders (UK)
- The UK government approved Dong Energy's plans to develop the 245 MW Westermost Rough wind farm off the N-E coast of England (UK)
- Scottish and Southern Energy (SSE) halted plans to build the 378 MW Kintyre offshore wind farm off the Scottish coast for a variety of reasons including a lack of wind resource (UK)

[41] This score is to acknowledge the Dutch entrepreneurial activities abroad in the absence of strong domestic market. The function Market formation is assessed in the later part of this report.

3.2. Knowledge development (F2)

New knowledge and mechanisms of learning are prerequisites of every innovation system. There are different types of knowledge (codified, tacit/technological) and various sources of new knowledge (R&D, learning by doing, learning by searching, etc.). To evaluate this function in the four analysed countries we studied the number and the type of actors involved in the knowledge development (knowledge institutes vs. industrial parties), as well as the type of knowledge developed (number of patents, publications, specialization along the value chain, alignment of produced knowledge with needs, etc).

3.2.1. Are there enough actors involved in knowledge development and are they suitable?

As demonstrated in sections 2.1.2 (Knowledge institutes) there are a growing number of knowledge institutes involved in research on offshore wind in all four analysed countries. While in the UK and Germany the scientific knowledge production is rather spread out over a great number of organisations, in Denmark and the Netherlands it is concentrated in a small number of institutes. With regards to their competencies as judged by their track record of published articles, the Danish University Alborg and DTU and the Dutch TU Delft rank highest in terms of number of journal publications. These organisations are therefore known worldwide for their scientific expertise on offshore wind energy. In Germany, IWES and Forwind (Oldenburg, Bremen and Hannover) are the research and education base of the country, whereas the UK works on catching up by involving growing number of universities in the offshore wind research and publication process.

The structural analysis (section 2.4.1 knowledge infrastructure), the analysis of functional pattern (see Box 2 for examples), as well as our qualitative research, further reveal that while public research provides insight[42] into a wide range of topics, such as models of wind turbulence, deep sea geology, turbine efficiency and oceanic wind patterns; it is the industrial players that develop the bulk of the needed technological knowledge. This knowledge actually drives the system development. The patent pattern shows greatest activity in the categories of vessels and wind motor by Vestas and Siemens, but there are also many new entrants in these areas who experiment with new designs and in so doing make the field very dynamic and competitive.

In line with the opinion of our interviewees, we can therefore conclude that there are enough competent actors that can develop both codified as well as tacit types of knowledge in all four analysed countries. Points of attention from the perspective of national TIS's are the following: firstly, the differences in concentration of codified knowledge production may imply for the UK and Germany the possible risk of insufficient focus and critical mass because of the distribution of resources in knowledge development. In Denmark and the Netherlands, on the other hand, there might exist the likelihood of insufficient diversity and variety in scientific knowledge production. As much as the dispersed model is useful for the training of future engineers all over the country, it does not seem sufficient for the provision of advanced education that is closely linked with research (Staffan Jacobsson, 2012). A concentrated model may lead knowledge development in the field more efficiently, and make it more visible and accessible to companies who want to cooperate. A

[42] Codified knowledge very well visible in the form of scientific publications.

minimal amount of focus and critical mass is also necessary to contribute to and compete in the international knowledge development.

Secondly, because of the dominance of the tacit, technological dimension of knowledge in innovative activities and the complexity of the technological trajectory, there may be a tendency for a geographical concentration of innovation. The particular dominance of multinationals such as Vestas and Siemens in the production of technological knowledge on wind turbines is very important for the system development and also as a European counter-balance for competition with Asia or the US. However, such dominance is not without risks, especially when taking a European or national perspective. One of these risks is the likelihood of a monopoly and all its implications, such as high prices and high entry barriers for newcomers. Fortunately, according to the 2011 data (e.g. EWEA, 2011a) this risk is balanced by the presence of a number of new entrants in that area. Their emergence is necessary to create variety in the number of technological solutions. The offshore wind market is too immature to just rely on a few large players.

3.2.2. Is the knowledge sufficiently developed and aligned with needs?

As showed in the structural analysis and as discussed above, codified (scientific) knowledge on offshore wind in the four analysed countries is produced by public research organisations, while technological (tacit) offshore wind knowledge is developed by large industrial players in their in-house R&D facilities. Both pools of knowledge (tacit and codified) expand as judged by the growing number of publications, journals and countries involved in offshore wind research, as well as by increased numbers of new products and solutions on the market (see for example section 3.4.2 on physical infrastructure/wind turbines). Also in the opinion of the interviewed stakeholders there has been enough knowledge developed in Europe on offshore wind. According to many of them, the research focus should now shift to making the technology cost effective, particularly in relation to wind turbines and cables.

Our analysis and review of knowledge activities of the various actors (Box 2) show that the four analysed countries seem to 'specialise' in the development of technological knowledge in the particular areas of the value chain: Germany and Denmark in the wind turbine technology while the Netherlands in the construction of wind farms and foundations. While in Germany, Denmark and the Netherlands there is a longer tradition in offshore wind knowledge development, the UK is only now developing its national capacity by converting its fossil fuel oriented research programmes into renewables related curricula, with offshore wind as one of the themes (section 2.1.3 educational organisations). No specialisation can yet be observed in the UK in any particular knowledge area, rather the attempt seems to be to keep up with rapid market developments and train specialists who could operate and manage the newly built wind farms. These circumstances as well as a specific consultancy culture may have been the reasons why the UK has the most consultancies involved in advising on offshore wind out of all the analysed countries (see section 2.1.5 support organisations).

From the European perspective, as taken by the stakeholders, there is indeed a lot of complementary knowledge developed in Europe, and the countries complement each other in their expertise and production of relevant knowledge. From the national perspective, however, it seems that countries are dependent on each other's knowledge. The UK particularly, with its sizeable market and not very extensive knowledge development, needs to rely on the knowledge activities of Denmark, the Netherlands and Germany. In the Netherlands, on the other hand, the poor offshore wind market may cause the academic knowledge production to lose its competitive edge, as a consequence of hindered interaction with, and insufficient feedback from, commercial innovation activities. To make good use of the *domestic* knowledge, Dutch actors would need to continue applying it to building foreign farms (as is the case in the field of foundation placing, where TU Delft works closely with van Oord and Ballast Nedam).

We also conclude that sources of technological innovations in the field are not directly related with scientific breakthroughs at university. The analysis suggests that the real opportunities to innovate in offshore wind may actually come from advancements in R&D equipment, infrastructure and operation of the wind farms. This might imply that the codified knowledge on offshore wind is not very well aligned with the actual industrial needs.

3.2.3. How does the function score?

Based on this analysis we evaluate the function F2 - knowledge development at the level of excellent (5) in Denmark, strong (4) in the Netherlands (to acknowledge publications) and Germany (to acknowledge patents) and moderate (3) in the UK. The interviews evaluated this function highly even though the national activities in this area where not too strong. In so doing they wanted to emphasise that countries have good access to the European pool of knowledge on offshore wind, and lack of significant domestic activities in that area, e.g. in the UK, does not hinder the functioning of the national TISs.

3.3. Knowledge diffusion (F3)

Knowledge exchange is essential for innovation and for the build-up of innovation systems. It takes place in the process of interaction. In emerging systems the interaction takes the form of bi- and tri-lateral collaborations. In more mature innovation systems, networks emerge and they play a role in diffusion of knowledge in the system. To asses if there is enough knowledge exchanged between different actors' groups e.g. science and industry, or users and industry, and across geo borders in the four analysed countries; we looked at the number and type of networks and tried to assess the general accessibility of knowledge. We complemented our findings on tacit knowledge diffusion with insights from qualitative research based on interviewing actors.

3.3.1. Are there enough different types of networks through which knowledge can diffuse?

Our analysis of different types of networks (section 2.2) demonstrated that knowledge networks based on collaboration on journal articles are not very extensive but rather sparse, with most co-authorship within the country, and with very poor involvement by industry. The collaborations on European research projects are much more frequent than on journal articles and with a more substantial involvement by industry. The UK, Denmark, the Netherlands and Germany emerge as most active collaborators on research projects in Europe. All four countries also have strong national research networks (such as Flow, Forewind or OWA).

Furthermore, even though most technological knowledge is developed by large industrial players in their in-house R&D departments, and despite the fact that the knowledge bases of these industries and knowledge institutes do not always coincide, companies in Denmark, Germany and the Netherlands do keep strong ties with universities. Denmark in particular, has close ties between public research organisations (such as Risø and DTU) and industry (Vestas) (Staffan Jacobsson, 2012), and German universities are involved in a number of programmes in close cooperation with industry (as presented in section 2.2.1 on knowledge networks). Universities in these countries and in the Netherlands are valued for the number of specialised offshore courses, and they also provide industry with an easy access to good students who are then trained in-house and provided with hands-on experience. In the UK universities and other knowledge institutes do not yet have a good link with industries because, as many interviewees pointed out, they do not produce enough commercially-minded people. To address the problem, attempts have been made in 2011 to prepare a special report examining career options in the UK offshore wind sector, featuring exclusive research, individual case studies, courses and employer information.

All four countries have good industrial cooperation, such as between utilities and companies, with an increased collaboration between institutes form European countries along the value chain. Also lobby/political networks are strong and well established in all four countries and at a European level. EWEA is an important European provider of a diverse platform for contact and collaboration on offshore wind across geographical boarders.

The value of a good network is recognised in all analysed countries. It is considered critical for the financing of new projects and finding a sufficient number of partners, such as risk insurers and banks, who can make the project bankable. In general there is, therefore, a sense of a relatively good level of knowledge diffusion in the offshore wind sector. Parties know each other and, if necessary, through partnerships and common projects they have the possibility to gain access to each other's knowledge. In Denmark the Offshore Centre Denmark plays a particularly important role in the process of bringing incumbents and start-ups together at common events and pre-arranged meetings. However, the sharing of knowledge is not fully public and freely accessible. Particularly companies are wary of sharing their technological knowledge for fear of losing their competitive advantage. This is reflected by increasing efforts to protect innovations by patents.

The geographical concentration and regional interactions may be related to the tacit, technological dimension of knowledge production. From the company perspective, knowledge is embodied in technologies, infrastructures and human resources. Due to its tacit and cumulative nature, this knowledge is very actor-specific and difficult to copy by others. To transfer tacit knowledge, close and intensive face-to-face contact between humans and organisations is needed, and geographical proximity is a vehicle to accommodate this type of communication. Knowledge accumulates at the regional level because key mechanisms through which knowledge diffuses across organizations are often spatially bounded.

3.3.2. How does the function score?

In view of the above discussion, and taking into account the opinion of the interviewees, we conclude that there is a good offshore wind network that crosses national borders, even though connections with universities are mainly local. We assess the function F3 –

knowledge diffusion in Denmark and Germany as excellent (5), strong in the Netherlands (4) and moderate in the UK (3).

Box 3. Selected examples of knowledge diffusion events in the four analysed countries in 2011

- Alstom Grid commissioned a 25 MW HVDC Demonstrator at its facilities in Stafford - a milestone in Voltage Source Converter (VSC) technology. The technology is required to deliver onshore the electricity generated from the Round 3 offshore wind programme and is critical to the creation of a robust European Supergrid (UK)
- Danish blade supplier LM Wind Power in cooperation with French turbine manufacturer Alstom have developed the world's longest wind turbine blade (DK)
- MAKE Consulting has published its annual Wind Turbine Trends report which provides a review of the current state of wind turbine technology evaluates new areas of innovation within the wind power industry and assesses the commercial impact of these trends. The report delivers a comprehensive component level analysis of a commercial, utility-scale horizontal axis wind turbine while maintaining a systems level perspective on the cumulative impact of strategic design decisions (DK)
- Professional training programme on offshore wind started in Den Helder (with TU Delft and ECN) (NL)
- Municipality expressed an ambition to develop a knowledge centre on offshore wind in Den Helder (NL)
- An EWEA 2011 conference on offshore wind took place in the Netherlands (NL)
- Powercluster project funded by EU with the goal to learn from experiences of oil and gas industry (NL)
- The Federal State of Bremen expressed ambition to make Bremerhaven and Bremen the leading competence centre and production area for offshore wind energy in North-West Germany (DE)
- Siemens opened UK Wind Power Research Centre at the University of Sheffield (DE-UK)
- Windpower Monthly created a special report examining careers options in the offshore wind sector, featuring exclusive research, individual case studies, courses and employer information (EU).
- Windpower Monthly launched Windpower Offshore, a free weekly email bulletin covering the latest news from the global offshore wind sector (EU)

3.4. Guidance of the search (F4)

Guidance of (or providing direction to) the search is a function that relates to all activities within innovation systems that can influence the visibility and clarity of the specific 'wants' among the users of technology. It is fulfilled either by industrial or governmental actors and provides a broad direction to the way in which financial resources are allocated. Therefore, to assess guidance of the search we have analysed the type of actors and their activities; impact of soft institutions (the level of governmental commitment, presence and reliability of policy goals and vision, expressed expectations); and influence of hard institutions (presence and quality of regulatory regimes, policy instruments and permitting procedure).

3.4.1. Are there enough and suitable actors who provide guidance of the search?

Offshore wind technology is still expensive compared to the fossil fuel technologies so its commercial operation in all four countries still is, and for the time being will remain, strongly dependent on nationally-financed support schemes such as obligation schemes or feed-in tariffs (either from the government budget or paid by the end-user). This strong dependence on national governments, that are not always stable in their commitments, negatively influences guidance and holds a risk of reduced legitimacy in which case foreign companies benefit the most from national efforts.
Industry, however, through its involvement and activities may also contribute to providing guidance of the search. Our analysis (section 2.2 actors, Box 4) shows that the offshore wind industry in the four analysed countries is well developed and it is also determined to

continue its offshore wind activities in expectation of a big market and potential great return on its investments. The involvement of large offshore incumbents who diversify their business to offshore wind, as well as the growing number of new entrants in the area of turbine design, drive the system development regardless of the fragmented offshore wind policies in European countries. Persistency of, particularly, Dutch industry to enforce governmental commitment to the development of the system needs to be mentioned here. In 2011 the Dutch industry closed a so-called Green Deal with the government in which the latter committed to supporting the field[43]. However, critics argue that the Deal is only meant to camouflage the fact that the Dutch government lacks both vision as well as determination to act and take its earlier renewable energy commitments and obligations seriously.

3.4.2. Do the soft institutions provide enough guidance of the search?

Governmental commitment, its policy goals and visions about growth and technology design are important informal, soft types of institutions that have major impact on the guidance of the search.

Our analysis of the soft type of institutions (section 2.3) as well as the activity patterns of the governments in the UK, Denmark, the Netherlands and Germany (see Box 4 for selected examples), reveal that the German government has the most clear and relatively consistent commitment to offshore wind among the four countries. In particular its decision to phase out nuclear power in the next 20 years[44] serves the large-scale renewable market well, in which offshore wind has a significant share. This commitment provides entrepreneurs with great security with respect to planning and investing. It also makes German firms such as Siemens, Hochtief, OWT, and PNE international market leaders. Denmark has a new government (started autumn 2011) [45] which wants to set the goal to 50% of energy from wind and other alternative energy sources[46]. This raises hopes among the offshore wind industry for better times and good levels of taxes on coal and gas. In the UK offshore wind is a crucial element of the government's plans to reduce the carbon intensity of the power sector, increase energy security and provide affordable energy to consumers. In the Netherlands, according to the stakeholders' interviews, the current government does not have a clear vision or a stable framework in support of renewable activities. For this reason the guidance of the search provided by the government on the development of the domestic market is almost absent. Still Dutch constructors do belong to the group of international market leaders but, contrary to the German firms, they are not backed by the national government. This holds considerable future risks for the Dutch, and also to some extent for the Danish, in case Germany and the UK continue to support national industry.

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[43] Key concepts in this Green Deal included a substantial cost reduction through innovation and policy changes, strategic growth of the offshore wind market, achievement of the climate goals, as well as further experimental and shaping of the legislation.

[44] The plan concerns 17 of its nuclear power plants — which have met around 20% of its electrical power.

[45] http://www.denmark.dk/en/menu/About-Denmark/Government-Politics/ accessed 27 Apr 2012.

[46] At the moment of finalizing the revision of this report the New Danish Energy Agreement outlined the framework for the Danish climate and energy policy until 2020 and the direction until 2050. According to this agreement CO_2 emissions in 2020 will be 34 % less than they were in 1990. Energy consumption will decrease by 12 % in 2020 compared to 2006. Around 35 % of the country's energy will come from renewable sources and almost 50 % of electricity will come from wind. It has also been decided to build a total of 3300 MW new wind power. A part of it is two new large offshore wind farms at Kriegers Flak between Denmark and Germany (600 MW) and at Horns Reef off the west coast of Jutland (400 MW). http://www.offshorewind.biz/2012/04/16/new-danish-energy-agreement-makes-denmark-safe-investment/ accessed 27 Apr 2012.

The national policy goals expressed in the NREPs and driven by the common 20/20/20 EU goals on climate change, differ per country (see section 2.3 institutions). Even though some of our interviewees doubt whether the goals will be realised (the interviewees did not believe in the power of non-compliance mechanisms). Still, from the guidance perspective, the goals do constitute relatively stable drivers for the development of the offshore wind system. They also provide space for industrial activities, as an outcome of which there emerge common expectations of a large market and huge potential. What the goals do not do is provide any guidance with regard to grid improvements. There are different circumstances regarding grid integration in the four countries under study. The national governments lack a consistent and coordinated (at the European level) vision on how improvements in reliability and integration of the grid should be carried out. At the same time, there is a strong need to develop a pan-European grid and a cross-Europe regulatory framework and trade policies. Stakeholders believe that a coordinated effort in this respect will strongly drive the development of a European offshore wind TIS. Currently the EU took some preliminary steps towards harmonised grid integration measures. The first being a memorandum of understanding that was signed by ministers from 10 EU countries to develop an offshore grid that would serve entire Northern Europe.

3.4.3. Do the hard institutions provide enough guidance of the search?

In our structural analysis (section 2.3 Institutions) we have demonstrated that the four analysed countries differ between each other with regards to their regulating regimes and a set of offshore wind policy instruments. The UK, Danish and Dutch stakeholders all look up to the well-functioning German feed-in tariff. The tariff allows energy providers to be paid for all dispatched energy regardless of its amounts. The UK regulatory framework for offshore wind (Renewable Obligation Scheme ROC) also works well, but our interviewees considered the German scheme more generous and providing less uncertainty for the industry. Most criticised for not supporting the relatively ambitious policy goals was the Dutch scheme. The scheme is based on a tendering procedure and implies that offshore wind needs to compete with lower cost renewable technologies. This makes it unlikely that new offshore wind farms will be developed (except for the ones which were approved in previous tender rounds). In Denmark, the interviewed stakeholders strongly emphasised that the heavy energy taxes on renewable electricity are very problematic. They suggested that removal of these taxes would make wind able to compete with fossil fuels and would provide a clear guidance of the search in Denmark.

All the four countries also suffer from increasingly long and non-unified across Europe permitting (consenting) procedure, which causes that projects get stuck in the planning system. There is further lack of common European trade code and uniform standards. The costs differ, so do subsidy schemes and targets. All these issues make it especially hard for the larger multinational companies that are active on international markets to operate effectively.

Box 4. Selected examples of events influencing guidance of the search

- Expressed doubts whether investment costs would go down (more turbine supply, more vessels available) or go up (material scarcity, far offshore projects) (UK)
- The UK renewables sector expressed belief that the offshore wind would play a crucial role in meeting a new target to reduce carbon emissions by 2025 by 50% based on 1990 levels (UK)
- A UK government advisory body said that the UK government needs to limit its offshore wind plans as they are too expensive.
- The UK government launched a task force to examine ways of reducing the cost of the UK's offshore wind programme (UK)
- The UK Government has issued assurances that offshore wind farm developers would be entitled to compensation if leases or agreements-to-lease awarded to them are withdrawn by the Crown Estate (UK)
- Offshore wind expected to receive a huge boost in Denmark under the newly elected government's target for half of the country's total electricity demand to be met by wind power by 2020 (DK)
- A report released by the government-appointed Commission on Climate Change Policy claiming that the offshore wind will be set to form the cornerstone of an energy revolution that would see wind energy account for 60-80% of Denmark's electricity needs by 2050 (DK)
- In 2011 Denmark's wind industry faced a big challenge: its energy policy, implemented in 2008, expired. Expected is that Denmark would expand its offshore wind capacity as part of its plan to meet half of its electricity needs from wind energy by 2020 (DK)
- The industry (>50 companies) and the Dutch Wind Energy Association (NWEA) convinced the Dutch government to sign the Green Deal Offshore Wind Energy (NL)
- 5.2 GW ambition formulated in NREAP considered no longer objective for Dutch government, hardly any expectations from the government (NL)
- Dutch government was criticised for putting more emphasis on the operating support needed for the wind farms than on the benefits (employment) for industry/the country (NL)
- Dutch government considered a quota system for after 2015 but uncertainties arose as to whether the system would be designed in such a way (as the UK did) that offshore wind would get a chance (NL)
- Innovation Platform expressed an opinion that the Netherlands should focus on offshore wind (and biomass options and domestic heat conversion) (NL)
- Essent (RWE) moved away from offshore wind (NL)
- Industry urged government to join projects and support infrastructure to develop home market (NL)
- Expectation expressed that the Germany's offshore wind farms, being built to replace most of the nuclear reactors closing in the next decade, are heading to miss construction targets because of delays in connecting turbines to the power grid (DE)
- E-ON and RWE, the biggest German utilities, have threatened to halt investment in wind projects unless obstacles are removed, which RWE blames mainly on slow permitting and problems with acquiring cables and transformer stations (DE)
- The construction of an offshore grid in the German part of the North Sea cannot be implemented under current regulatory system, according to European grid operator TenneT (DE)
- Memorandum of understanding signed by Ministers from 10 EU countries to develop an offshore grid to serve Northern Europe (EU)

3.4.4. How does the function score?

Overall, we conclude that the European goals provide a strong guidance for the offshore wind system development. The differing and changing national obligations less so, but they do give some space to the industry to experiment. Germany due to commitment of the government and a well-functioning feed-in tariff, has the strongest guidance of the search (function 4) out of all analysed countries. We evaluate it at the level of: excellent (5). The UK is evaluated at the level of: strong (4), Denmark is rated at: moderate (3) while the

Netherlands is: weak (2) (non-existent on the part of government but strong on the part of industry).

3.5. Market formation (F5)

New technologies, sustainable in particular, being often far from optimised, frequently have to compete with very efficient matured and cheaper incumbents solutions. They need protected space to develop. Formation of a niche market with a set of supporting incentives is one of the possibilities. On the other hand the formation of a market around such emerging technologies and systems is a sign that they are developing and acquire increased legitimacy. To evaluate market formation in the four analysed countries we have looked into the size of the market (installed capacity, wind farms consented and planned) and the supporting incentives.

3.5.1. Is the size of the market sufficient and are there adequate incentives?

According to the EWEA (2011a), the European offshore market in 2020 will reach 6.9 GW, and that year the installed capacity will reach 40 GW. Some of our interviewees, however, doubt whether this potential will be realised. They believe the impact of the EU renewable goals is rather limited because of the limited power of the compliance mechanisms. The interviewees also expect that due to the current financial crisis renewables will not get much attention and definitely not much priority from national governments. Finally, according to the interviewees, the EU directives do not mandate how these goals should be achieved. That might imply that many countries may decide to continue with fossil fuels and buy renewables from abroad (on the condition that other countries have a surplus). From a legal perspective the targets, as specified by the EU Directive and in the national action plans, are mandatory. Countries will have to take measures to meet the goals. What is important for the governments now is to decide to what extent the development of offshore wind is crucial to meet their overall 2020 target. If it is, as in the UK, then there is a strong binding incentive from this target and hope for the offshore wind sector.

All countries consider offshore wind as potentially huge, a multi-million euro market, able to provide hundreds of jobs domestically. The UK market is the world's biggest, and therefore also considered sufficient for many international players. It is being driven by the Renewable Obligation Certificates regulation. Many actors think that the ROC system provides a huge payback and may be seen as a model subsidy scheme but it is not without limitations. Within the scheme energy companies are obliged to provide defined amounts of renewable energy. Failure incurs a fine, which is transferred as revenue to others who do meet the requirements. That means that there is no fixed price per ROC. This fuels the business of tracking the prices and to keep companies up to date, but is not beneficial for the offshore wind industry because no one produces more energy than necessary and after a certain level price flattens out. Furthermore, the ROC system does not encourage the supply chain development, so large volumes of supply chain are going through Germany and Denmark while construction activities go via the Netherlands. There is hardly any manufacturing in the UK and the risk for the UK is that Germany may very soon take over the leadership with regards to the size of the market. In Germany itself offshore wind is an extremely attractive market with huge orders. Commitment from the government and a well functioning feed-in tariff substantially support its development. Danish offshore market is not considered very big compared with the UK or Germany but with lots of experience and political will to achieve 50% of energy from renewables within which 30%

of the total is from offshore. The Dutch market is very limited with no new farms under construction in 2011. Three large-capacity ones for a total 1.8 GW (Bard 1 and 2 and Q10), are consented and planned for 2012/13 but they were a decision of the previous government. The current government does not have any concrete plans after 2012.

3.5.2. How does the function score?

Based on these considerations we conclude that the Netherlands and Denmark, without further steps, are in a danger of losing market shares at a European level. Denmark, due to low increase in installed capacity and consented projects, and the Netherlands, due to lack of new installations and for not supporting market development and innovative technologies. The UK has high ambitions but not too many consented projects, while Germany seems to be a true leader in market formation. We therefore evaluate the function F5 market formation: in Germany at the level of excellent (5), in the UK as strong (4), while in Denmark and in the Netherlands weak (2).

Box 5. Selected examples of events influencing market formation

- In 2010 the UK was the undisputed leader in offshore wind, with many expecting that it would retain that position in Europe until well beyond 2020 (UK)
- Plans to install 3.5 GW of wind plants in the UK waters by the end of 2012. This is almost as much as the country has built onshore over the past 20 years (UK)
- The House of Commons Committee on Climate Change has described the UK's plans to develop 18 GW of offshore wind by 2020 as "a big gamble" (UK)
- Danish energy group Dong's focus shifted towards offshore wind markets, particularly the UK, after the announcement that it is pulling out of the Midtfjellet onshore wind-farm development in Norway (DK)
- Having been shut out of the UK's Round 3, and with ambitious renewables targets of its own, Dong angled for a role in France's offshore programme and remained open to buying into other zones around the North Sea (DK)
- Government subsidy granted for two operational projects (NUON/Shell, Eneco) (NL)
- € 4.9 billion government subsidy (operational support for 20 years) available for 3 projects to be developed: 2 from Bard (since August 2011: Typhoon Capital and utility HVC), one from Eneco, Q10 (NL)
- Permits have been granted for three other locations, but no subsidy available (NL)
- The government proposed a 10% cut in its support for onshore wind and a 5% cut for offshore wind (UK)
- Offshore wind development gathered momentum in Germany, with 80MW of capacity - in the shape of the first sixteen 5 MW turbines of the 80-turbine Bard 1 project in the North Sea - being online in December 2011 (DE)
- Dong Energy has acquired the development rights to the Borkum Riffgrund West 1 project from Energiekontor (DE/DK)
- Vattenfall has announced plans to build the 576MW Sandbank 24 offshore project off the German island of Sylt in the North Sea (DE)

3.6. Resource mobilization (F6)

Resources in all forms: financial, human and physical are necessary as basic input to all of the activities within the innovation systems. Without these resources systems are unable to function. To evaluate the function resource mobilisation we have studied: availability of financial resources; availability of competencies and expertise and availability of physical infrastructure.

3.6.1. What is the availability of financial resources?

Based on the structural analysis (section 2.1.5 supportive organisations), analysis of functional pattern (see Box 6 for selected examples) and qualitative research, we have no strong evidence that the availability of financial resources (capital costs) has been very problematic. According to our interviewees however, availability of funds (capital costs and R&D funds) does create a significant barrier. The interviewees also emphasised that due to the crisis, the risks for banks in all four countries are very high so many banks have decreased their loans, which causes many projects to not be financially viable. This implies that increased numbers of banks and (international) financial organisations need to be involved in the financing of one project (bank clubs) and a number of insurers to take the risk on board (KPMG, 2010). At the same time, however, data shows that the number of wind farms is growing steadily and according to EWEA (2011c) there are more banks that are willing to finance offshore wind farms.

Germany and the UK seem to have the most certain financial situation of all four countries. The financial certainty in the UK is assured until 2014, thanks to the locked-in commitments (with an average of 2 billion pounds per annum). In expectation of a big market and following the ambition of the UK government to make offshore wind a part of the UK renewable energy mix – work started on identifying additional sources of capital that would allow for funding the Round 3 projects (2017-2022)[47]. The UK also allocated significant investments in harbour infrastructure. It is a similar situation in Germany. Amongst the reforms, the government confirmed that the state-owned development bank KfW will provide up to €5 billion of financing to 10 offshore wind farms, and also announced that the planned reduction in subsidies for offshore wind developers will be delayed from 2015 to 2018[48].

In Denmark there are many pension organizations who invest a great deal in wind (financial and industrial investments). They see a long-term profit from such investment because turbines are considered very reliable and wind is generally perceived as a safe business. By comparison, in the UK there is not enough confidence in technology (turbines are expensive so low risk turbines are preferred) which causes many pension funds to be locked-in to financing traditional big infrastructural projects. These projects still seem to the pension funds more reliable than the renewable offshore projects.

In the Netherlands two large offshore wind farms are going to be constructed in 2012/13 but offshore wind remains to be seen as a very expensive option in the near future. Despite large subsidies from the Dutch government, wind power provides merely 4 percent of Dutch electricity. The Dutch government is willing to invest in innovation to bring down the costs of offshore wind energy, but prices must come down considerably before large scale investments can again be supported. For the time being therefore, the government has stopped the subsidies for offshore wind power generation.

Overall, to meet their national renewable energy targets all four countries will face financial challenges. Increased levels of investments will be necessary for new wind farms and incentives for technology development (through R&D and demonstration), grid

[47] http://www.thecrownestate.co.uk/media/229356/owdf_04_01_finance_group_paper.pdf accessed 27 Apr 2012.
[48] http://www.businessgreen.com/bg/news/2100019/germany-enjoys-surge-offshore-wind-investment accessed 27 Apr 2012.

improvements and integration, harbours adjustments and development of clusters around the ports.

3.6.2. What is the availability of competencies and expertise?

With exception of the UK, availability of human resources at the moment of this analysis is not extremely problematic in any of the analysed countries. It may become a problem when the offshore wind system develops to meet the European renewables targets. Currently, in Germany and Denmark offshore wind is an attractive, well-paid field, but in the Netherlands young people are rather careful not to take the risk of educating themselves in a field that does not seem to have a big future. In the UK it still pays better to work for oil and gas than for the offshore wind industry. This has very serious consequences for the UK who has a rapidly growing market but a quite underdeveloped domestic value chain. The UK faces a serious shortage of personnel with all types of offshore wind skills and experience. Particularly electrical and structural engineers who can install and manage the new wind farms are of severe scarcity. In the remaining three countries the situation is better, still specific expertise is missing. In the Netherlands there is a lack of electrical engineers. Germany needs more engineers with practical experience while in Denmark marine engineers are in deficiency. Furthermore, Denmark expects a generation gap when current professionals will have to retire, and there will be either too few new experts, or they will have little practical experience. Shortage of skilled labour causes companies, being unable to find the experts at the universities, to try to attract them from other companies, which serves for a relatively high level of mobility of offshore wind experts in Europe.

As demonstrated in the structural analysis (section 2.1.3. educational organisations), all four countries make attempts to address the problem of shortage of personnel with offshore wind experience by designing an increasing number of offshore wind educational programmes and courses. There is also intensifying European collaboration on education, which is a sign of the need to harmonise and coordinate the system at the European level. However, the courses and programmes are quite recent and very few compared to the needs. Europe-wide funding cuts for the higher education sector pose an additional threat.

3.6.3. Is the physical infrastructure sufficient?

Three issues repeatedly dominate the discussion in this area in all four analysed countries: the cost of technology, problems with cable infrastructure, and issues around the grid. Our structural analysis (section 2.4.2 physical infrastructure) and the events collated for this function (see Box 6 for examples) confirm that these are problematic areas.

For technology the challenge is to develop the next generation of inexpensive but reliable turbines and foundations. This implies, on the one hand, the need for innovations (and the corresponding investment) but on the other hand the need to reduce costs. Standardisation is seen as one of the possible strategies to deal with the challenge because it allows for reduction of costs and automation of production (now, the lack of common design standards causes that manufacturers produce a great variety of turbine designs). A critical issue for the development of new turbines is the availability of rare earth elements: neodymium and dysprosium, which reserves are limited and hence there is an insufficient supply of these elements.

Grid stability and capacity is another serious issue in all of Europe. The European grid needs to be modified and renovated in a way that it can accept larger amounts of renewable energy. There are also difficulties with securing grid access with financial implications relating to where the connection takes place. Research suggests, for example, that connecting wind farms into hubs before connecting them to the grid is more cost-effective than connecting them individually but no common grid strategy is as yet developed. All four countries have works underway to improve their part of the grid. The indecisiveness of many national governments with regards to the future energy mix, and in particular the renewables, makes any common action rather difficult.

With regards to the cable installation, there are issues with fluctuating copper prices and a general lack of cables, especially the HV cables. Cable companies think that the problem with delivery of cables is because the orders reach them too late in the process of wind farm installation. The companies argue that cable orders should be made at the stage of the project development; otherwise there is no space to deliver the order. For cable companies offshore wind is not the only industry they supply with cables. They also provide to other sectors so large amounts are not always available at short notice, and if they are, the costs are incomparably higher making the costs of wind farm project suddenly higher than anticipated.

Scarcity of vessels is not found to be very problematic at the moment of analysis. However, many interviewees emphasised that innovations are needed in the area of vessel adjustment to operation in deep waters >50m, and specialisation in performing different tasks. Now around 50-60 different types of dedicated vessels are needed for one farm installation. In the future, if the offshore wind system develops, the scarcity of specialised, deep water vessels may become a serious constraint.

Finally, all countries have a great harbour capacity, particularly the Netherlands, the UK and Denmark who actively served the oil and gas industry. However, almost all harbours need to be adjusted to be able to assist the offshore wind operations. Some, such as Rotterdam, face societal opposition because their adjustment to meet offshore wind standards would imply territorial extension and intensification of activities and what that entails – noise, transport and pollution.

3.6.4. How does the function score?

In view of this discussion we assess function F6: resource mobilisation in the following way: financial resources in the Netherlands at the level of weak (2), in Denmark moderate (3) and Germany and the UK strong (4). Human resources we rate at the level of strong (4) in Germany and Denmark, moderate (3) in the Netherlands and weak (2) in the UK. Physical resources we evaluate as weak (2) in the UK and moderate (3) in the three remaining countries.

Box 6. Selected examples of resources mobilisation events

- Report: thriving the UK offshore sector struggles to fill vacancies. Over the past year, a quarter of employers in the UK offshore wind sector reported hard-to-fill vacancies, compared with a national average of 3%. Applicants lacked the required experience in nearly half the cases reported, followed by insufficient skills (29%) or qualifications (14%) (UK).
- The UK government announced the creation of two funds totalling £30 million for companies developing innovations for the offshore wind sector (UK)
- A small harbour on the northern coast of Scotland better known for fishing and as a berth for the Orkney ferry was set for investment to turn it into an offshore wind and wave energy service port (UK)
- Dong Energy signed a €240 million loan deal with the Nordic Investment Bank (NIB) to help finance the 400 MW Anholt offshore wind farm (DK)
- The Nordic Investment Bank (NIB) is loaning Norwegian grid operator Statnett €165 million to finance a new subsea cable between Norway and Denmark (DK)
- The Danish Energy Agency has approved the acquisition by pension firms PKA and Pension Denmark of a 50% stake in the 400 MW Anholt offshore wind farm (DK)
- Vestas received money from the UK's £1.4 billion (€1.6 billion) Regional Growth Fund (DK/UK)
- Possibly extra €84 million from EU for new Eneco project (needs €400-450 million for investment) (NL)
- Meewind invested €150 million in Bard projects (NL)
- Limited capital available for grid extensions (Tennet) (NL/DE)
- Professional training program on offshore wind started in Den Helder (with TU Delft and ECN) (NL)
- Van Oord started its own training program. With underdeveloped home market, training seems to be essential to supply the international offshore wind market (NL)
- Opinion: with current low ambitions there are no constraints regarding vessels (construction, maintenance, logistics). Vessels could become a major constraint in the case of a new government trying to catch up with earlier formulated ambitions (NL)
- Opinion: global growth of offshore wind could potentially but not necessarily lead to scarcity of rare earth materials esp. neodymium en dysprosium, of which large quantities are required for direct drive permanent magnet generators used in several new turbine models (NL)
- Opinion: cabling could become a supply constraint as of 2015 (NL)
- Den Helder uttered ambition to become main harbour for offshore wind farms maintenance and logistics (NL)
- German offshore wind electricity got partly lost due to grid problems (Dutch Tennet needs money to strengthen German grid) (DE/NL)
- The €1.3 billion financing of the 400 MW GlobalTech1 wind farm in the North Sea closed, and is the biggest project financing in the offshore sector to date (DE)
- The German Meerwind project was the first offshore wind farm to be led by private investors from the pre-construction stage (DE)
- German developer Windreich acknowledged it is in discussions with car manufacturer VW over investment in one of its three permitted North Sea offshore wind projects (DE).
- European grid operator Tennet warned it might struggle to install further offshore connections to North Sea wind farms due to a shortage of cables and cash (DE/NL)
- Instead of heading for the bank, small wind developers are covering their equity needs for project development by inviting small investors to buy profit-participation rights known as Genussrechte (DE)
- One of the world's largest private equity firms and one of its largest infrastructure banks announced plans to plough billions of Euros into Germany's fast-expanding offshore wind sector, after the government announced offshore wind farms will play a central role in its plans to phase out the use of nuclear power plants (DE)
- The Meerwind project (288 MW, €863 million in long-term debt), closed in August. It was the first to take advantage of the new €5 billion program set up by KfW, Germany’s development bank, and the first to be brought to the market by a pure financial investor, Blackstone. It was supported by Eksport Kredit Fonden (EKF), the Danish export-credit agency (DE)

3.7. Legitimacy creation (F7)

For new technology to be economically successful it needs to become a part of the incumbent regime or even overthrow it. This causes the emerging technologies to be perceived by the incumbent actors as a serious threat. Incumbents therefore tend to oppose and resist the novelties. To overcome their resistance, advocacy coalitions are needed that would put the new technology on the political agenda, lobby for favourable conditions and resources and by doing so, create legitimacy for a new technological trajectory. To evaluate if there is enough creation of legitimacy we have therefore analysed the level of resistance to technology, the perceived level of competition between technologies and the extent to which the hard and soft institutions increase legitimacy.

3.7.1. Do the hard and soft institutions increase legitimacy?

The climate change debate and the climate targets, esp. the 20/20/20 goal including the NREPs provide firm legitimacy for renewables in general and for offshore wind in particular. Although, on the one hand, offshore wind is just one of the alternatives to fossil fuels and so it has to face competition from other renewables in gathering attention and financial resources (Jacobsson and Karltorp, 2012); on the other hand, it is the fastest growing renewable in the next decade. Target achievement without substantial offshore wind energy is therefore deemed to be hard in all four analysed countries.

In terms of legitimacy in specific countries, much depends on the extent to which offshore wind is needed to meet the national RES target or the extent to which the national governments see offshore wind as a means to the development of national industry and creation of jobs. Germany and the UK have clear national visions on offshore wind and well developed support programmes to achieve the targets. These soft types of institutions are therefore considered by the interviewees as contributing most to increasing the legitimacy of offshore wind in the two countries. In Denmark offshore wind is also seen as a major future contributor to the energy production and with the new greener government, has a serious chance to develop. In the Netherlands: the lack of vision, absence of any consistent programme and poor subsidy scheme, are the factors most limiting the legitimacy of this renewable.

The soft institutions, especially the expectations regarding the robustness and availability of technology and markets, are in our view very optimistic, and given that the long testing period of the design has not yet taken place, they are also difficult to evaluate. They may turn risky if the system up-scales too rapidly. Not meeting the expectations may create tensions. Risk perception is another issue that is of great importance for such a very capital intensive sector as offshore wind. Banks are often risk-avoiding and unwilling to finance wind farms comprising new wind technology without track record. At the time of the financial crisis many banks lowered their offshore wind energy project funds making it difficult to install a wind farm without involvement of more financial organisations. Furthermore, uncertainties about the grid connection and overall lack of alignment of the vision on grid improvements additionally hinder the legitimacy creation.

3.7.2. Is there resistance towards the technology, project set up or permit procedure?

In none of the analysed countries is there significant opposition to offshore wind farms as long as the wind turbines are not visible from the shore and there is no huge impact of construction on the local public. Municipalities worry about societal resistance when farms in the vicinity of 20km from shore are being planned. Particularly in Denmark there is good acceptance of the technology because it brings revenues and jobs. In Germany, which has the strictest environmental requirements, some marine biologists criticised the noise pollution from drilling and installing the foundations and pillars. To deal with the problems as they arise, continuous environmental assessments and ongoing testing are conducted in parallel to installation and operation of the farms. Germany expects this to create a competitive advantage with respect to complying with international standards that other countries might not be able to fulfil yet. In the Netherlands, legitimacy of the offshore wind technology is relatively low due to political resistance, high costs and competition for space in the North Sea.

3.7.3. How does the function score?

In view of this discussion and accounting for interviewed experts' opinion we rate function F7: creation of legitimacy at the level of moderate (3) in the Netherlands and strong (4) in the UK, Germany and Denmark.

Box 7. Selected examples of legitimacy creation activities in 2011

- Limited interest at global level in investing in offshore wind compared to other RES technologies.
- Opinion:14% binding RES target still there, but (crucial) role offshore wind not recognized (NL)
- Opinion: offshore wind leads to creation of jobs (NL)
- Opinion: offshore wind as an alternative for onshore wind (NIMBY) (NL)
- Opinion: offshore wind not being an alternative for onshore wind (too expensive) (NL)
- Opinion: coal power plants become less efficient with more offshore wind, on a net base more CO_2 (NL)
- Permits for two farms not granted because of harbour interests and birds (NL)
- US entrepreneur and TV celebrity Donald Trump has upped the ante in his fight against a 100 MW offshore wind farm planned for the Scottish coast (UK)
- BWEA predicts that the development of offshore wind industry will eventually add some £60bn to the UK economy and save 800 million tonnes of CO_2 emissions. The development of the sector will also create between 67,000 and 115,000 new jobs (UK)
- Construction of offshore wind farms off Germany's northern coast in the North and Baltic Seas faced significant delays, even as the country's utility companies tackle one project after another abroad. Things have fallen so far behind that government officials are happy to see anything happen at all (DE)
- Opinion: According to HSBC, the global offshore market is predicted to grow at approximately 29 percent between 2009 and 2020, with Germany set to be a major contributor (DE)
- TenneT informed the German government that construction of grid connections for offshore wind farms in the North Sea was no longer possible, either at the present pace and under current conditions (DE)
- Opinion: Denmark would be forced to allocate several more offshore wind zones to meet the expanded new wind target laid out by the elected government, predicts Dong chief executive. Added to its ambitions for biomass, the new wind goal (50% electricity from wind) means Denmark would likely blow its EU-mandated 31% renewable-electricity target out of the water, further boosting the green credentials of a country that pioneered the wind-energy business in the 1970s and 1980s, and plays

3.8. Functional dynamics in 2011

Figures 15-18 give an overview of system function fulfilment in the four analysed countries. The numbers on the figures present the strength of the functions: 1-absent, 2-weak, 3-moderate, 4-strong, 5-excellent.

Figure 15. Overview of system function fulfilment in the Netherlands

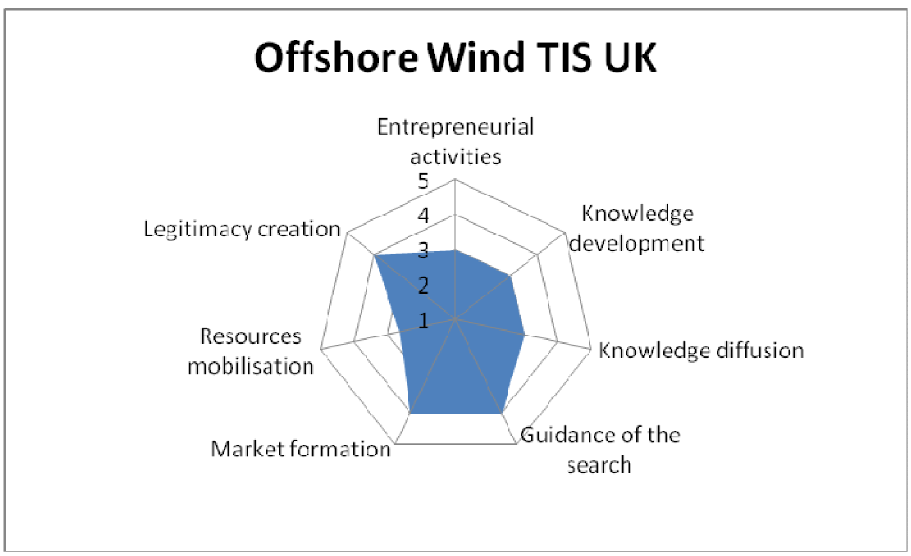

Figure 16. Overview of system function fulfilment in UK

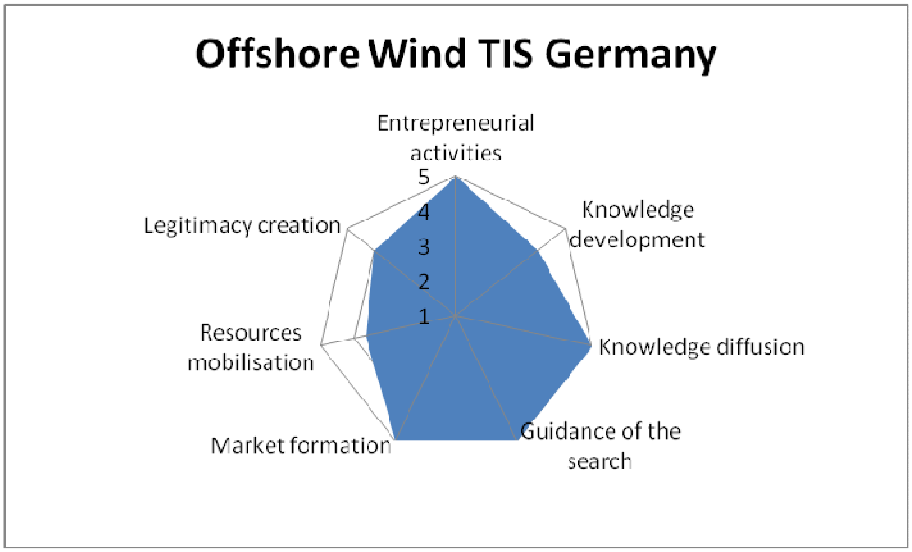

Figure 17. Overview of system function fulfilment in Germany

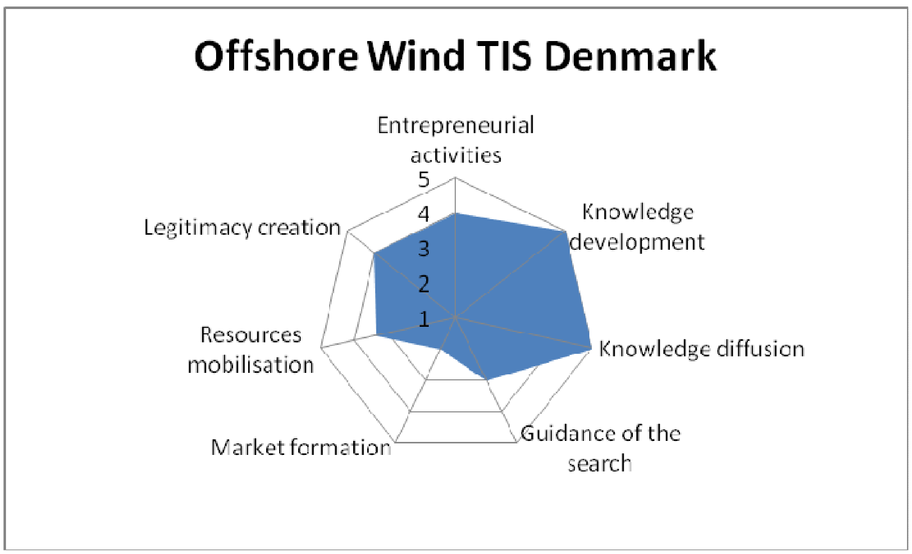

Figure 18. Overview of system function fulfilment in Denmark

Comparison of the functional pattern of the four TIS's at hand (Figure 19) reveals that entrepreneurial activities score relatively well in all four countries but are strongest in Germany. In knowledge creation it is Denmark that excels while the UK scores relatively low. Knowledge diffusion is strongest in Germany and Denmark but low in the UK. Guidance of the search is by far the strongest in Germany, strong in UK but very weak, almost absent in the Netherlands. Market formation processes are by far the best in Germany, not bad in UK but very weak, almost non-existent in the Netherlands and Denmark. Resources mobilisation is equally weak in all four analysed TISs while legitimacy creation scores on average slightly higher than resources function but still equally low in all four places.

Based on the functional analysis we can therefore conclude that there is not only a strong need for, but in fact already an emergence of, a European offshore wind innovation system. Figure 19 shows the extent to which the national TISs contribute to the European innovation system. A very strong indicator of European system emergence is the visible complementary specialisation of the four countries in entrepreneurial experimentation and knowledge creation. While in the national context this specialisation may have rather negative implications such as loss of national legitimacy or leakage of financial resources, from the European perspective it works to the advantage of the system. Creation of a European market, integrated grid and common regulatory framework would be very beneficial for the European system and would further significantly enhance the system development.

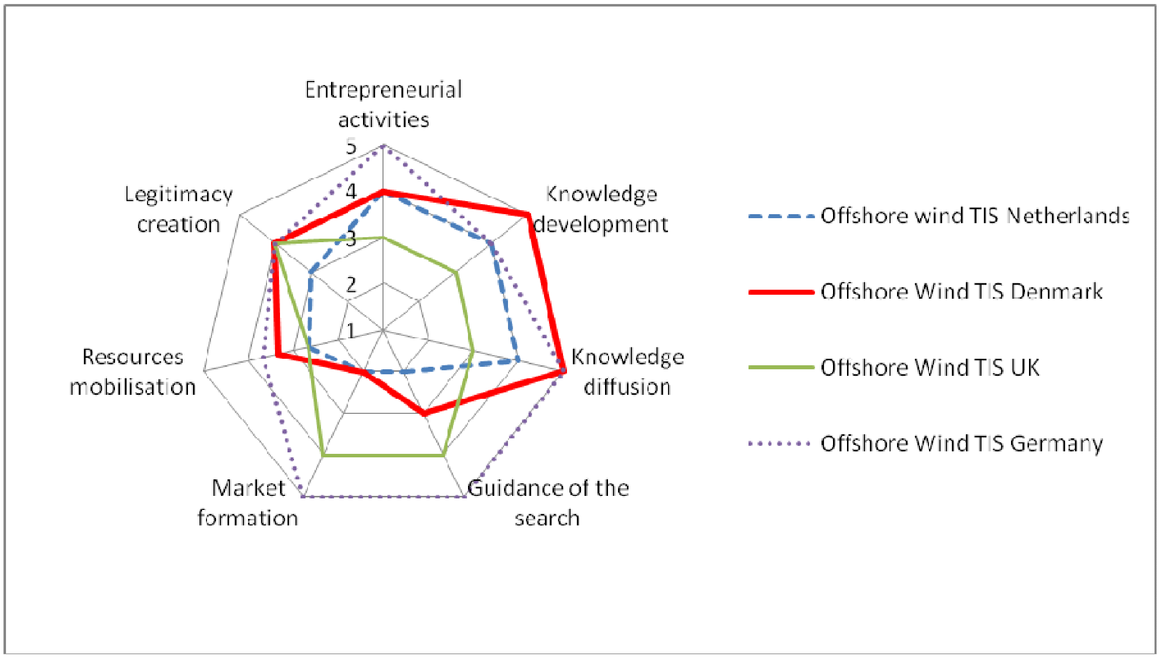

Figure 19. Comparison of system function fulfilment in all four analysed countries

4. Discussion and conclusions

Having analysed the structure of the four offshore wind innovation systems (Section 2) and having assessed how they function (Section 3), we can proceed to the identification of weaknesses that hinder their development. In a specifically defined innovation system four types of systemic problems can be identified: actors, institutional, infrastructural and interaction problems. They are identified based on the analysis of the factors that hinder specific functions. These factors are then attributed to the structural components of the system (mapped in Section 2), which makes it possible to specify which of them need to be altered and how, in order to improve the performance of the entire system. This provides a very systematic input to policy decision making and the design of an integrated tool that can address the weaknesses in a more orchestrated manner.

4.1. What hinders the functioning of the innovation systems?

Our analysis shows that in the Netherlands entrepreneurial activities (F1) are most hindered by a limited home offshore wind market caused by the lack of political support. Also the changing renewable policy of consecutive cabinets results in changing regulatory regime and ineffective support programmes that fail to support the ambitious goals. Denmark since autumn 2011 has a new greener government, which raises hopes among entrepreneurs for new pro-renewables politics[49] but the 2011 low rate of increase in installed capacity did not stimulate much of entrepreneurial activity. In the UK entrepreneurial activities are held up by the underdeveloped value chain, in particular lack of any manufacturing capacity and poor availability of skilled labour. This causes a quite significant presence of large foreign incumbent companies in the UK value chain and little space for national new entrants. In Germany, where the government is committed and the feed-in tariff does its job, entrepreneurial activities are not hindered by any specific factor.

Even though offshore wind is an emerging field there seems to be enough knowledge produced (F2) (in Europe) not to create a serious barrier for the system development. However, the tacit character of knowledge that drives the offshore wind innovation system has several implications. One of them is that it causes a lack of cross-fertilisation between knowledge produced at universities and by industrial parties. This is most visible in the Netherlands. Knowledge institutes have a high publication record and they claim to work closely with industry, but the industry does not patent and knowledge produced at universities (e.g. on rotor techniques) does not always translate into a national manufacturing capacity. This divergence unnecessarily delays the system development. Limited governmental commitment resulting in a poor domestic market and unfavourable R&D conditions, as well as funding cuts for higher education, are two other factors that are responsible for the slowing down of the knowledge development in the Netherlands. In Germany the knowledge base is fairly strong; especially technological knowledge is well developed which is observable in the high level of patents by Siemens. The codified knowledge is produced in Germany in a great number of institutes. It is difficult to assess the extent to which this dispersed model hinders the knowledge development. It may have negative implications for creation of critical mass and for stimulation of education that is close to research. In the UK the knowledge base on offshore wind does not have a long tradition and is only now being organised. It is also quite fragmented and not very strongly linked to national strategies, which may account for its overall lower impact and education of skilled labour. The number of educational programmes is growing but insufficiently to the needs of the industry. Lack of specialisation in any of the offshore wind areas and shortage of manufacturing capacity in the country may be both the outcome of and the reason for the poor knowledge base in the UK. In Denmark the knowledge base is in good shape (knowledge institutes with good publication records and patents by Vestas), but what creates unnecessary uncertainty for companies who plan R&D investments in Denmark is that the R&D programmes are negotiated annually as part of the government's fiscal budget and not on a longer term perspective.

Function knowledge diffusion (F3) is mainly hindered by the dominance of the tacit/technological type of knowledge and the problematic transfer of university knowledge to a specific context of application. Germany and Denmark are exceptions. Both countries' wind industry sector employs great numbers of people and there are large and informal industry-university networks. Hence diffusion of technology in both countries is comparatively good. In the Netherlands, however, the small domestic market does not allow for an immediate feedback from the industry to university; while the UK quite strongly depends on the knowledge transferred from abroad and has not yet developed any significant expertise that can be diffused to other countries. In the situation when the

[49] See footnote 46.

offshore wind innovation system is driven by the tacit /technological type of knowledge, companies in all four analysed countries are, understandably, not very eager to share their know-how in fear of losing their competitive advantage.

Guidance of the search (F4) is in all four countries hindered by the uncertainties around wind turbine technology, vessels, cables supply (especially HV cables), increasing costs per kWh, and a protracted permitting procedure. Also, since offshore wind is a young technology it strongly depends on political support. The national governments however are not always stable in their commitments. Particularly in the Netherlands, the unfavourable government policy for renewables and lack of a suitable support scheme negatively influence the guidance of the search. The Green Deal negotiated by the Dutch offshore wind industry is often criticised for being a camouflage for the government's lack of vision and determination to act and take its earlier renewable energy commitments and obligations seriously. This does not provide any strong guidance. In Denmark, guidance of the search was in 2011 hindered by the lack of strong commitment from the earlier government but is improving ever since new 'green' cabinet was selected in October 2011 and released the New Danish Energy Agreement. In the UK the administrative barriers, such as a great number of authorities involved in the authorisation procedure and slow approval rate, have negative impact on the guidance of the search. In Germany this function is not visibly hindered. However, lack of clear grid strategy and of a truly European market, as well as long consenting procedures, are issues that hold up the guidance of the search in all four analysed countries. Problematic for the guidance is also the perception of the 20/20/20 goals as not really binding and not specifying how the targets should be met.

For market formation (F5) there is a serious technical barrier on how to feed-in the extra offshore wind power into the existing grid, and how to bring the costs of the technology down to acceptable levels. In the future for all countries, the availability of cables and specialised vessels that can work on deeper waters may also become problematic. Furthermore, all four analysed countries suffer from the shortage of particular types of experts (mainly engineers) and availability of funds. Non-aligned institutions, especially regarding the grid, strongly hinder European market formation. There is no strong belief in the noncompliance mechanisms and ambiguity about how the targets should be met. Furthermore, the UK ROC system is not considered as very supportive to the supply chain development and there is no manufacturing capacity in the country. For the UK the need to adjust the harbours and organise incentives for the development of clusters around the ports is an additional challenge. In Denmark the current low rate of increase in installed capacity and consented projects is a barrier to market formation. In the Netherlands the national policy and poor support scheme force the major offshore wind contractors to get involved in international projects. Financial crisis and related increased perception of risks additionally cause that banks reduce their renewable energy projects funds, hence more financial organisations and more insurers are needed before the project is made bankable. This trend is common in the UK, Denmark, the Netherlands and Germany and impacts market formation in all four analysed countries.

Resources mobilisation (F6) is mostly hindered by financial crisis and growing risks, availability of finance in Europe, lack of skilled labour, in particular engineers and insufficient educational courses that can train experts. Furthermore, grid access and capacity is a major issue, and so is the lack of regulations and of a vision on possible grid improvement strategies. Also availability of cables caused by late orders and the price of copper, as well as insufficient harbour infrastructure, influence legitimacy creation in all four analysed countries. In the UK lack of a strong knowledge base and manufacturing capacity, as well as lack of an offshore wind tradition cause the field to not be seen as attractive by young people. In the Netherlands perception of the technology as being very expensive significantly slows down resources mobilisation.

Legitimacy creation (F7) is hindered by: competition with other renewables; competition for space in the North Sea and lack of binding targets beyond 2020. Uncertainties around grid connection and lack of common vision also have a (negative) impact on legitimacy creation. The dominance of large utilities as owners and operators of national projects may have some additional negative bearings, mainly on social acceptance of the technology applied in projects, which is partially based on access to public finance by smaller parties. If the funds begin to be streamlined to the large utilities this may raise issues with legitimacy of the system. Particularly in the UK it also holds a risk of reduced legitimacy in which case foreign companies benefit most from national efforts. In the Netherlands lack of vision and an adequate support scheme play the biggest role in hindering legitimacy creation.

4.2. Systemic policy challenges in the European offshore wind innovation system

Offshore wind technology holds the potential for tackling major energy issues, climate change problems and creating jobs and economic growth. However, according to the JRC report (2011) the electricity production costs associated with this technology are still higher than for conventional technologies. This creates a serious barrier for its further diffusion. The analysis presented in this report showed that from an innovation perspective offshore wind is a young and very dynamic system driven by the engineering knowledge developed by in-house R&D centres of the industry. To develop further, though, three innovation system's processes need to be improved by policy. These processes include: resource mobilisation (as described by function F6), market formation (function F5) and legitimacy creation (function F7). These processes can only be enhanced by policy through intervention into the structural elements that build the innovation systems. We, therefore, group the related specific policy challenges into four aspects: institutional, actor-related, infrastructural and issues concerning connectivity within the system. These policy challenges require a systemic, coordinated policy effort at a European level if the system is expected to contribute to the goals of climate change reduction and stimulation of green growth. In this section we briefly discuss the challenges.

Institutional alignment of national policies, instruments and regulatory framework is an absolute precondition that can pave the way for other policy enhancements. The varying support schemes, the long and often complex consenting procedure, as well as lack of training standards, need to be tackled to allow for achievement of the national targets and ambitions. The development of a uniform grid strategy for Europe and the establishment of a pan-European electricity trade code are of particular importance. Most importantly, however, offshore wind requires stable and long-term political support. This support is of utmost relevance to the reduction of the perceived risks (by banks for example), to addressing of the issue of competition with other renewables and to the increase of the attractiveness of the sector as a whole. Clarification of- or provision of a guideline on- how the national targets should be met and what the non-compliance mechanisms are, would supply additional incentives to the system's development.

Addressing issues related to the absence of specific actors in the value chain as well as improving the capabilities of the present ones, should be the second major aspect of the policy dedicated to offshore wind. The analysis shows that particular countries specialise in specific aspects/phases of the value chain as well as in specific aspects of knowledge. A pan-European collaboration that would turn this specialisation into an advantage and help create a complete and highly competent European value chain could become very beneficial to the offshore wind system in general and to the European strategic position in the field in particular. Although the national value chains seem quite dynamic as can be judged by the share of incumbents and new entrants, policy attention should, however, still be focussed on keeping the balance and also on stimulating innovation from medium and smaller enterprises by e.g. removing various barriers to entry, or reduction of risks and uncertainties. Another actor-type of challenge, of great urgency and significance to offshore wind system development, is that of addressing the shortage of skilled labour (especially engineers), by the provision of high quality educational courses and various training activities.

The third element of the systemic offshore wind policy concerns infrastructural aspects: knowledge, physical and financial. With regard to the knowledge infrastructure – provision of R&D on both technical (turbines, specialised vessels, grid and cables) as well as non-technical issues of offshore wind energy (cost-effectiveness of technology) should receive priority. Concerning physical infrastructure – further support of national activities devoted to the enhancement of harbour infrastructure should be provided. The European coordination of work on grid capacity enhancements is also critically important. A pan-European action plan on grid infrastructure would be especially advantageous. Regarding financial infrastructure, the availability of finance to both R&D as well as the capital costs of wind farm installation is essential. Such financial support could take the form of capital grants, production tax credits and tax reduction for offshore wind, soft loans, credit guarantees etc.

Lastly, although there are no major challenges related to interaction within the offshore wind innovation system, nevertheless, the connectivity between some actors could be enhanced. This refers especially to the formal collaboration between science and industry in order to diminish the current divide between codified knowledge produced by universities, and technological knowledge produced by industry. In particular industry needs incentives that would help them increase their confidence in sharing knowledge while knowledge institutes are in need of good stimuli to produce knowledge that industry finds useful and applicable. Collaboration with oil and gas producers on the active transfer of their experience to the offshore wind system would provide additional advantages.

An orchestrated systemic policy instrument, for the offshore wind innovation system, built around the four types of challenges, would, in our view, be essential to the diffusion of offshore wind technology, and it would significantly contribute to the achievement of the European 2050 vision of moving to a competitive low carbon economy (EU, 2011).

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ANNEX 1

Technological Innovation System Analysis

A manual for analysts

Introduction

The most important insight that has dominated the field of innovation studies in recent decades is the fact that innovation is a collective activity. It takes place within the context of a wider system. This wider system is coined 'the innovation system' or 'the innovation ecosystem'. The success of innovations is to a large extent determined by how the innovation system is build up and how it functions (Hekkert et al., 2007, Bergek et al., 2008).

The concept of the innovation system stresses that the flow of technology and information among people, enterprises and institutions is key to an innovative process. It stresses the interaction between actors who are needed in order to turn an idea into a successful process, product or service in the marketplace.

Many innovation systems are characterized by some flaws that greatly hamper the development and diffusion of innovations. These flaws are often labeled as system failures or system problems. Intelligent and evidence based innovation policy therefore evaluates how innovation systems are functioning, tries to create insight in the system problems and develops policies accordingly (Smits and Kuhlmann, 2004,Klein Woolthuis et al., 2005,Van Mierlo et al., 2010,Negro, S.O., Alkemade, F., Hekkert, M.P., 2011).

This manual contains instructions and explanations on the analysis of technological innovation systems for policy purposes. While literature about technology and innovation is abundant, the need for a single reference specific to the analysis of technological innovation systems for policy purposes prompted the development of this manual. This manual is not a definitive reference on the topics covered and is not meant to substitute for texts or journal articles. The manual is intended to serve as a convenient guide for any policymaker performing analysis of technological innovation.

The manual is based on the Technological Innovation System approach as developed by Utrecht University in cooperation with other European institutes like Chalmers University in Sweden and EAWAG in Switzerland. Technological Innovation System is a concept developed within the context of the Innovation System approach focusing on explaining the nature and rate of technological change. A Technological Innovation System can be defined as the set of actors and rules that influence the speed and direction of technological change in a specific technological area (Hekkert et al., 2007, Bergek et al., 2008, Markard and Truffer, 2008).

The purpose of analyzing a Technological Innovation System is to analyse and evaluate the development of a particular technological field in terms of the structures and processes that support or hamper it. The basic steps that are taken are the following:

First, we analyse the structure of the innovation system. These are the actors and rules that make up the system. Second, we analyse how the system is functioning. We will use seven system functions that stem from theory and are empirically validated as indicators. We analyse each function, but also the interaction between the functions. Finally, after we have established at what state of development a technological innovation system is, we can analyse the system problems that block the well functioning of the innovation system.

All innovation systems can be characterized by the same basic building blocks or components. These are actors, institutions, networks and technology. Examples of actors are organizations responsible for education, R&D, industrial activities, and consumers. Examples of institutions are supportive legislation and technology standards. Examples of networks are the linkages between organizations in research projects and advocacy coalitions. Technology is part of the innovation system as it enables and constrains the activities of actors in the innovation system. We will present a categorization of all components that are important in a Technological Innovation System and we will develop indicators to measure the size of these components. In this manual these will be applied to the case of the offshore wind innovation system as an example.

Even though different innovation systems may have similar components, they may function in a completely different way. Therefore, measuring how innovation systems are functioning is considered as the big breakthrough in innovation systems research. In a number of scientific articles lists of evaluation criteria are presented to evaluate how innovation systems are functioning. These assessment criteria are labelled in the literature 'functions of innovation systems'. In Hekkert et al. (2007) (2007) the following functions of innovation systems are put central:

1. Entrepreneurial activities,
2. Knowledge development,
3. Knowledge exchange,
4. Guidance of the search,
5. Formation of markets,
6. Mobilization of resources,
7. Counteracting resistance to change.

The important difference with the *structure* of the innovation system is that these system *functions* are much more evaluative in character. Focusing on functions allows us to address the performance of an innovation system. In other words: the structure presents insight in who is active in the system, the system functions present insight in what they are doing and whether this is sufficient to develop successful innovations.

In addition to quantitative indicators, the functioning of an innovation system needs to be assessed by experts or key stakeholders that are active in the innovation system.

The reason to evaluate the innovation system by means of expert opinions is that it is impossible at the moment to solely evaluate an innovation system based on quantitative criteria. The reason for this is that technologies and regions are different from each other and that it is impossible to define an optimal configuration of the innovation system. Consequently, benchmarking innovation systems is difficult; what works in one country may not work in another country. Furthermore, the development of an innovation system often depends strongly on the competition in other parts of the world and very often has very technology specific dynamics. For some technologies much more R&D funding is necessary than for others. Therefore, the best way to assess the functioning of the innovation system is by involving a sufficient amount of experts in the evaluation.

However, just asking how the innovation system scores on the different functions is not sufficient. The seven functions are quite broad in their description and a much more detailed set of indicators is necessary to make sure that the answers by the respondents are comparable. The function knowledge development can for example be measured by asking about the quantity, the quality and the direction research activities. Therefore, very specific diagnostic questions need to be developed to assess the functioning of innovation systems.

In summary, in order to monitor the development of emerging technologies, this manual offers 5 steps that will be described in detail to perform the innovation system analysis. The first steps describe the mapping of the structure and functioning of the innovation system. After establishing the stage of development, step 4 and 5 identify the main barriers and provide handholds for appropriate policy making.

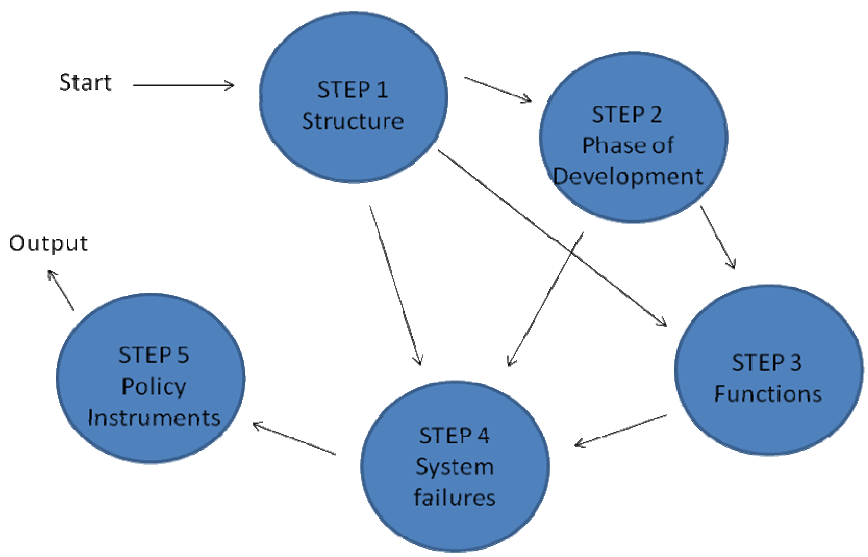

Figure 1. Schematic representation of the 5 steps in analyzing a technological innovation system for policy analysis

Step 1 Structural analysis

The structure of the innovation system consists of innovation system components. We distinguish between four types of components:

1. Actors: Actors involve organizations contributing to a technology, as a developer or adopter, or indirectly as a regulator, financer, etc. It is the actors of a Technological Innovation System that, through choices and actions, actually generate, diffuse and utilize technologies. The potential variety of relevant actors is enormous, ranging from

private actors to public actors, and from technology developers to technology adopters. The development of a Technological Innovation System will depend on the interrelations between all these actors.

We distinguish between the following actors categories:

a. Knowledge institutes

b. Educational organizations

c. Industry

d. Market actors

e. Government bodies and Supportive organizations

2. Institutions: Institutional structures are at the core of the innovation system concept. It is common to consider institutions as 'the rules of the game in a society, or, more formally as the humanly devised constraints that shape human interaction. A distinction can be made between formal institutions and informal institutions, with formal institutions being the rules that are codified and enforced by some authority, and informal institutions being more tacit and organically shaped by the collective interaction of actors. Even though informal institutions have a strong influence on the speed and direction of innovation, they are impossible to map systematically. Therefore, in the mapping of the innovation system structure, we focus on the formal policies that are in place that are likely to affect the development of the focal technology.

3. Networks: The central idea of the innovation system framework is that actors function in networks. In the case of networks it is interesting to map the geographical focus of the networks. Do the networks have a localized or globalized character?

4. Technological factors: Technological structures consist of artifacts and the technological infrastructures in which they are integrated.

In figure 2 the actors and institutions are represented that play a role in the development, diffusion and implementation of the technology. The different actors interact with each other in networks that develop or diffuse the technology. However these interactions are not represented in the figure. All together the four pillars (actors, networks, institutions and technology) form the structural components of the innovation system.

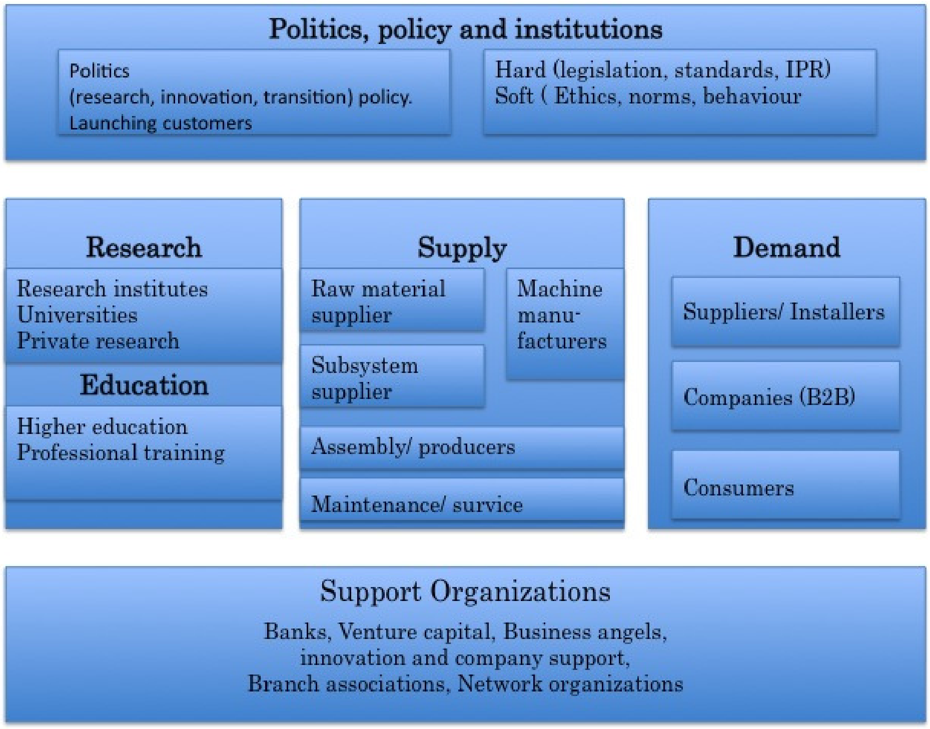

Figure 2. Structure of the innovation system (based on Kuhlmann and Arnold, 2001)

Determining the system structure

To create insight in the structure of the innovation system the components (Technology, actors, networks and institutions) need to be mapped. The list below outlines the steps and questions that need to be answered, in addition to some key sources of information.

Technology; What are the technological trajectories?

Technological trajectory refers to a single branch in the evolution of a technological design of a product/service. As such, a technological trajectory is a set of technologies that consistently develop over time in certain direction. In this process an accumulation of knowledge takes place. Sometimes, different (and competing) technological trajectories exist.

Technologies also involve the techno-economic workings of such artifacts, including costs, safety, and reliability. These features are crucial for understanding the feedback mechanisms between technological change and institutional change.

Patent classifications can provide an overview of the set of technologies (and their trajectories) that is relevant for the TIS under study. An overview of the International Patent Classifications (IPC) can be found at the WIPO.

The most convenient overview of patent data is provided by the WIPO database that can be found at http://www.wipo.int. Alternatively, the EPO database offers free access to more than 70 million patent documents worldwide, containing information about inventions and technical developments from 1836 to today. Always use the advanced options for bibliometric searching.

Also the US Patent and Trademark Office (PTO) offers World-Wide Web (Web) access to bibliographic and full-text patent databases. The USPTO patent database can also be accessed at http://www.google.com/patents.

Actors; Who are the actors?

Industry; Describe the value chain of the different technological trajectories

Value chain analysis describes the activities within and around a set of organizations, and relates them to an analysis of the competitive strength of these organizations. Therefore, it evaluates which value each particular activity adds to the products or services relevant to the TIS under study. This idea is built upon the insight that an organization is more than a random compilation of machinery, equipment, people and money. Only if these things are arranged into systems and systematic activates it will become possible to produce something for which customers are willing to pay a price. Porter argues that the ability to perform particular activities and to manage the linkages between these activities is a source of competitive advantage.

In most industries, it is rather unusual that a single company performs all activities from product design, production of components, and final assembly to delivery to the final user by itself. Most often, organizations are elements of a value system or supply chain. Hence, value chain analysis should cover the whole value system in which the organization operates.

Please note that not every TIS contains a complete value chain!

Often consultancies, sector organizations and government organizations have information available on the different organization active in a sector. It is desirable to have an indication of size of the market in terms of total turn-over or number of employers.

Research**;** Describe the state of the knowledge system

Technological innovation systems differ greatly in terms of the knowledge base and learning processes related to innovation. First, knowledge may have different degrees of accessibility (Malerba-Orsenigo, 1997) i.e. opportunities of gaining knowledge that are external to firms. This knowledge may be internal to the sector (thus favoring imitation) or external to the sector (thus affecting the availability of technological opportunities to incumbents and new firms). In both cases greater accessibility of knowledge decreases industrial concentration.

The sources of technological opportunities markedly differ among technological innovation systems. In some cases opportunity conditions are related to major scientific breakthroughs in universities. Opportunities to innovate may often come from advancements in external R&D, equipment and instrumentation. Possibly, external sources of knowledge in terms of suppliers or users may play a crucial role.

a. Which parties develop knowledge?

   The codified knowledge base is well archived in the form of scientific publications. Several databases exist; the Science Citation Index, SCOPUS and Google Scholar. Of these, the Science Citation Index provides the most robust scientometric information. CORDIS, the Community Research and Development Information Service for Science, Research and Development, is the official source of information on the European framework programs; it offers interactive web facilities that links together researchers, policymakers, managers and key players in the field of research. This search allows you to search quickly and easily all CORDIS content at once. This data permits a detailed assessment of the collaborations among institutions within the fields under study and its growth over time.

b. Where are the knowledge producers located?

   Often, knowledge production is geographically concentrated in a relatively small number of locations. Especially when accessibility of knowledge is difficult, there is a tendency of increasing geographical concentration. If external knowledge is easily accessible, easily transformable into new artifacts and exposed to a lot of actors (such as customers or suppliers), then innovative entry may take place (Winter, 1984). On the contrary, when advanced integration capabilities are necessary (Cohen-Levinthal, 1989) the industry may be concentrated and formed by large established firms.
   The uneven distribution becomes clear when measuring the clustering of knowledge production. All publications contain one or more author addresses that can be used to map the geographical distribution.

c. How much knowledge is developed?

   The question of growth of knowledge is central in understanding patterns of innovation, and according to Bonaccorsi (2008) the direction of growth (converging or diverging) is a defining attribute of a sector. Opportunities for new developments are large when the knowledge base is fast growing and diverging.

d. What are the types of organizations involved in knowledge production?

   Knowledge production involves different types of actors with different roles; universities, companies, and governments. This Triple Helix model assumes the traditional forms of institutional differentiation among universities, industries, and government as its starting point. The model thus takes account of the expanding role of knowledge in relation to the political and economic infrastructure of the larger society (Etzkowitz and Leydesdorff 2000).

Education; Are the education needs met?

In important aspect of the functioning of an innovation system relates to the match between the educational system and the entrepreneurial needs. In most cases, it will be difficult to obtain information about the extent to which the educational system provides to the needs/demands of entrepreneurs and researchers (partly due to privacy issues). Only in rare occasions sector organizations or universities have labor market statistics available of graduates from universities.

A general indication of the match between the educational system and the entrepreneurial needs is provided by the intensity if university-industry collaborations in knowledge production as indicated by co-authorships. Also the existence of special professorial chairs at universities funded by companies can provide insight in the educational organization providing relevant skilled labor.

Market**;** What does the market look like?

The most important question concerning the nature of the market is related to the demand side; which organizations provide demand for the technology under study? Furthermore, is demand technology specific or not?

From Schumpeter to Porter innovation-thinkers have recognized the importance of an advanced market, of well articulated critical demand as a driving force for innovation. An important distinction here is the extent to which private companies provide demand in relation to the public (governmental) demand. Often, very generic government initiatives exist such as educating the consumers or highly specific initiatives like procuring new technologies.

Politics and policy**;** What are the policy goals related to the TIS?

ERAWATCH provides information on European, national and regional research policies, actors, and programs in the EU and beyond. The policy goals and instruments with respect to the Technological Innovation System are an important aspect in understanding the functioning of the TIS. Relevant questions here are; How big is the variability of policy goals? What kind of policies, regulations, programs are there with respect to the new technology? How reliable is the policy? (Is it based on previous programs, regulations, instruments or is it completely different)

Intermediaries**;** Which parties try to engage collaboration between different parties?

In the interaction between Universities, Governments and Industry there are many intermediary organizations that facilitate the exchange of knowledge and resources. In addition to ERAWATCH , which provides information on European, national and regional research policies, actors, and programs there are consultancies, sector organizations and government organizations that have information available on the intermediary organization active in a sector.

Networks; What does the network look like?

Network analysis views relationships in terms of networks of nodes and ties. Nodes are the individual actors within the networks, and ties are the relationships between the actors. The resulting graph-based structures are often very complex. Networks play a critical role in determining the way problems are solved, organizations are run, and the degree to which organizations succeed in achieving their goals. Using data from CORDIS (project collaborations) and SCI (co-authored publications) we can establish what kind of formal relations occurred in the between organizations related to the technological trajectory. A central question here is; Who are the central players in the system?

Step 2. Determining the phase of development

Structures involve elements that are relatively stable over time. Nevertheless, for many technologies, especially newly emerging ones, these structures are not yet (fully) in place. For this reason, scholars have recently enriched the literature on Technological Innovation Systems with studies that focus on the build-up of structures over time. The central idea of this approach is to consider all processes that contribute to the development, diffusion, and use of innovations as system functions. These system functions are to be understood as types of processes that influence the build-up of a Technological Innovation System. Each system function may be 'fulfilled' in a variety of ways. The premise is that, in order to properly develop, the system should positively fulfil all system functions.

The way of how the structure and the functioning of an innovation systems should be build up is dependent on the phase of development of the technology. If the technology is still in an early phase of development than the innovation system has a different structure and certain functions are more relevant than those for a more mature technology. In order to monitor an innovation system it is first important to determine the phase of development. This is necessary to be able to evaluate whether the innovation system performs well with relation to the phase of development.

If the technology is diffused to a certain extent then the TIS should be of a certain maturity. On the other hand a certain size of a TIS determines the extent of diffusion of the technology. To determine the phase of development of the technology and the TIS, the international TIS is positioned on the diffusion curve (see Figure 4). The diffusion curve of a technology describes the extent of diffusion on international level of the technology and has the shape of an S-curve. The curve describes the process of development, application and further diffusion of the technology. The S-curve can be divided into different phases. The first is the *pre-development phase* where a prototype is produced, i.e. the first evidence that the new technology works. Then in the *development phase* the first commercial application occurs where the new technology or product is sold for the first time and enters the market without subsidy. In the next phase, the *take-off phase*, the technology or product will be diffused on a larger extent and the market will grow further, i.e. *acceleration phase*, until saturation occurs and the degree of diffusion stabilizes, i.e. *stabilization phase*.

In order to determine in which phase of development the technology resides, diagnostic questions can be asked. If the answer is yes then the technology is in the next phase of development.

Pre-development phase: is there a working prototype?

Development phase: Is there commercial application?

Take-off phase: Is there a fast market growth?

Acceleration phase: Is there market saturation?

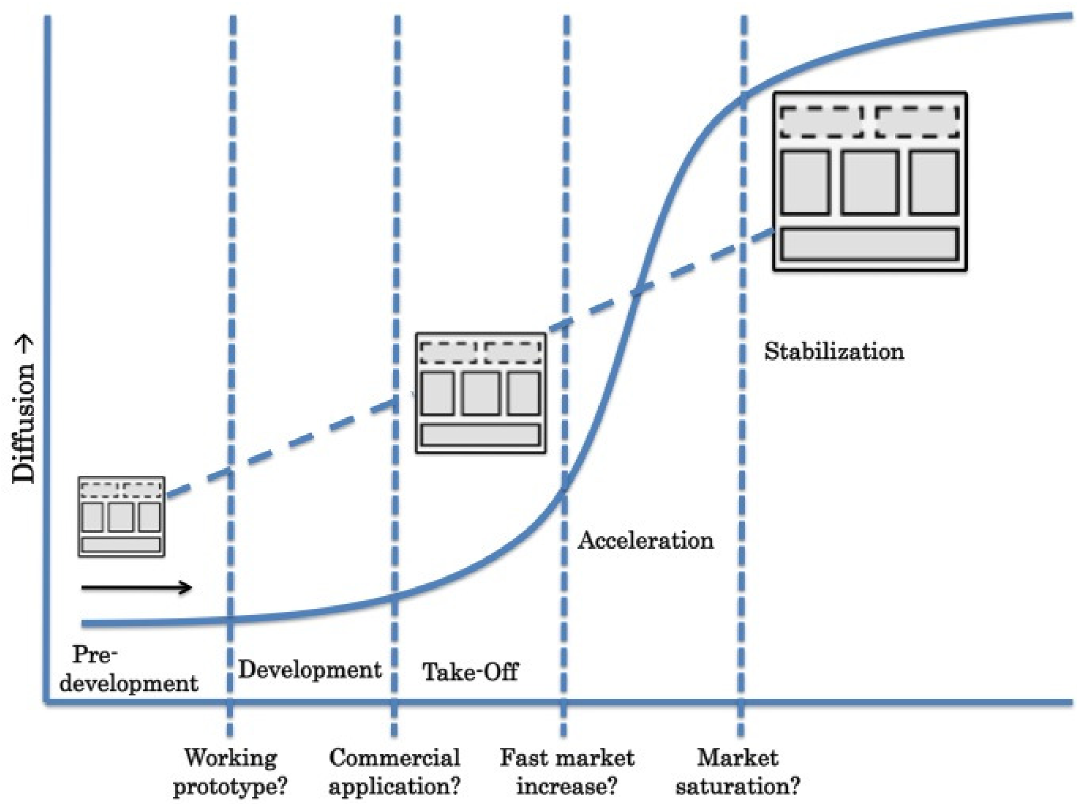

Figure 3. Phase of development

In each phase of development the structure and functioning of the innovation system is different. After determining the phase of development of the technology it can be determined whether the innovation system is build up in a correct way and whether it can make the move towards the next phase. The characteristics and criteria's that the structure and functioning of a system need to fulfil will be explained in the next steps.

Step 3. System functions

Even though different innovation systems may have similar components, they may function in a completely different way. Therefore, measuring how innovation systems are functioning is considered as the big breakthrough in innovation systems research. In a number of scientific articles lists of evaluation criteria are presented to evaluate how innovation systems are functioning. These assessment criteria are labeled in the literature as 'key processes of innovation systems' (system functions). In Hekkert et al. (2007) the following system functions are put central:

1. Entrepreneurial experimentation,
2. Knowledge development,
3. Knowledge exchange,
4. Guidance of the search,

5. Formation of markets,
6. Mobilization of resources,
7. Counteracting resistance to change.

The important difference with the structure of the innovation system is that these system functions are much more evaluative in character. They state *how* an innovation system is performing. The functioning of an innovation system needs to be assessed by *experts or key stakeholders* that are active in the innovation system.

The reason to evaluate the innovation system by means of expert opinions is that it is impossible at the moment to solely evaluate an innovation system based on quantitative criteria. The reason for this is that technologies and regions are different from each other and that it is impossible to define an optimal configuration of the innovation system. Consequently, benchmarking innovation systems is difficult; what works in one country may not work in another country. Furthermore, the development of an innovation system often depends strongly on the competition in other parts of the world and very often has very technology specific dynamics. For some technologies much more R&D funding is necessary than for others.

Therefore, the best way to assess the functioning of the innovation system is by involving a sufficient amount of experts in the evaluation by asking them very specific diagnostic questions, whether the amount of activities are sufficient and whether they form a barrier for the innovation system to further develop and move towards the following phase of development. Most of the data has already been collected during the structural analysis, but with asking the experts an assessment can be done about the quality of the innovation system.

Table 1. Overview of System Functions and diagnostic questions for analyzing the functioning of the Innovation System

Functions	Diagnostic questions	Sub-questions
F1-Entrepreneurial experimentation	Is there enough entrepreneurial activity?	- Are there sufficient and right type of actors that contribute to entrepreneurial experimentation? - Are the number and type of activities of these actors sufficient?
F2-Knowledge development	Is there enough knowledge developed?	- Are there enough and right type of actors who develop knowledge? - Is the amount and type of knowledge developed sufficient and aligned with needs?
F3-Knowledge exchange	Is there enough knowledge exchange?	- Are there enough of networks of different kind through which knowledge can diffuse?
F4-Guidance of the search	Is there enough guidance of the search?	- Are there enough and right type of actors who provide guidance of the search? - Do the soft institutions provide enough guidance? ❖ Is governmental commitment sufficient? ❖ Are the policy goals and vision in terms of growth and technology design clear and reliable? ❖ Are the overall expectations aligned and do they

		reduce uncertainties? - Do the hard institutions provide enough guidance? ❖ Are the regulatory regimes, policy instruments and permitting procedure supportive?
F5-Market formation	Is there enough market formation?	- Are the size of the market and the incentives sufficient?
F6-Resource mobilization	Is there enough resource mobilization?	- What is the availability of financial resources? - What is the availability of human resources? - Is the physical infrastructure sufficient?
F7-Llegitimacy creation	Is there enough creation of legitimacy?	- Do the hard and soft institutions increase legitimacy? - Is there resistance towards technology, construction process, and permit procedure?

Analysis

In this step the system functions need to be scored on a 5 point likert scale (1 = very weak and 5 = very strong) in order to identify how well each system function is fulfilled and which system function forms the largest barrier that should be targeted by recommendations.

In the spider-diagram below (Figure 4) the extent to which each system function is fulfilled will be represented. The system function with the lowest scores can be seen as the most problematic ones.

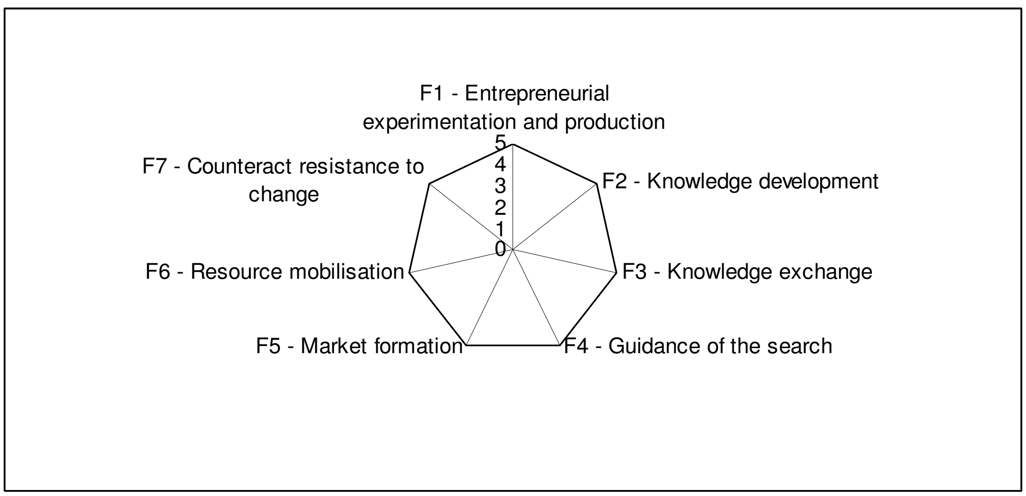

Figure 4. Overview of system function fulfilment

However in order to be sure which system function forms the biggest barrier we need to relate the presence and fulfilment of the system functions to the phase the IS is in. Not every system function is as important as other system functions in each phase.

The fulfilment of the system functions varies per phase of development of the technology. In each phase different system functions play an important role depending on the aim of the phase. The build up of the innovation system occurs over time throughout the phases which results that the fulfilment of the system functions is cumulative (i.e. more knowledge is build up). Therefore all system functions need to be fulfilled in order to support the build up of the TIS in question.

Figure 5 shows possible functional patterns per phase. The black arrows are the relations that occur in the current phase, whereas the grey arrows represent the relations that occurred in previous phases and are still occurring in order to further improve the development of the technology into 2nd or 3rd generations. In this way the system functions fulfilment differs over time but since the system functions influence and interact with each other they reinforce each other contributing to the build up of the innovation system.

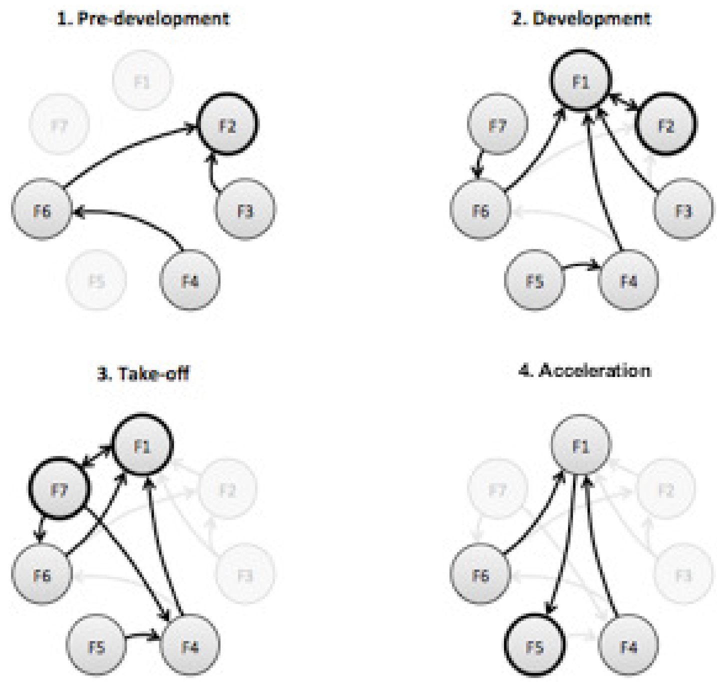

Figure 5. Functional patterns per phase

For the pre-development phase we expect that knowledge development is the most critical system function. This system function may be negatively influenced by a poor performance of other system functions, such as knowledge exchange, guidance of the search and resource mobilization. Thus these four functions deserve most attention in the analysis when in this phase. The other system functions are expected to be less influential.

For the development phase we expect that entrepreneurial experimentation is the most important system function as the first experiments and pilot plants are set up that will show whether the innovation also works in practice. All other system functions may positive or negatively influence this system function. So all system functions may be critical in this phase and will need to be thoroughly analysed.

For the take off phase, entrepreneurial experimentation and production is critical. In this phase entrepreneurs should really become system builders. Therefore counteract resistance to change and build legitimacy (F7) is also a critical system function. Guidance of the search, resource mobilization and market formation are important supportive functions. Knowledge development and exchange are most likely to be less critical in this phase.

For the acceleration phase market formation is the most important system function, as a growing market fuels the innovation system to develop and diffuse further. Supportive functions are entrepreneurial production, resource mobilization and guidance of the search. The other functions are most likely to be less critical.

If the most important or supportive system functions of a particular phase are missing or are unfulfilled then they can block the build up of an innovation system. By identifying which system function blocks the further development of the Innovation System, appropriate policy recommendations can be formulated to remove this barrier.

Step 4. Structural cause for functional barriers

The outcome of the previous analysis is the identification of a number of system functions that can form an obstacle for the progress of technological development. These obstacles can block the development and diffusion of the technology. In this step the causes for the hampering will be identified.

The causes can origin in the structure of the TIS. The system functions that are badly fulfilled are a manifestation of problems in the structure. By identifying where the problems are within the system the barriers can be removed. For example if function knowledge development is badly fulfilled than the cause could be related to the lack of knowledge institutes and universities that provide the appropriate courses to educate people that can work with the new technology. By identifying the problems in the structure these can then be removed or improved.

If the government develops policy to improve and facilitate the functioning of the TIS, then the new policy will be included in the structure which will influence the functioning of the system.

In order to find the causes in the structure of the system the following steps will be followed:

1. Determine which system functions are forming a barrier.
2. Determine for each system function which structural component forms a barrier. Look at the following structural components:
    a. Actors, different groups/parties
    b. Networks, relations and cooperation between parties
    c. Institutions (formal and informal regulations; these have not been elaborated on in step 4, so need to analyse them in depth here)
    d. Technology, the knowledge related to technology
    e. External factors/Context. For example competition between two TISs.
3. Describe the relation between cause and barriers. What are the functional consequences of the causes in the structure and what are the functional

consequences of the competition between several TIS? Do the barriers have to do with a lack of structural components or with lack of quality? What are the effects of the structural components on the functioning of the system – which system functions improve or become worse due to structural problems?

Step 5. Obstacles for policy goals

Innovation policy is about helping companies to perform better and contributing to wider social objectives such as growth, jobs and sustainability. There are many policy tools available to achieve this, ranging from establishing supportive framework conditions (e.g. human resources, an internal market, intellectual property) to facilitating access to finance, policy benchmarking and enabling collaboration or stimulating demand, for instance, through regulation, standards and public procurement.

However, the choice of policy instruments depends on the identified structural cause for functional barriers in the innovation system, as well as the precise goal of a policy and the geographical and technological scope of the TIS under study.

Therefore it is important to determine the *policy goal* of the respective innovation system because new emerging energy technologies provide different opportunities which can lead to different policy goals and changes of these goals over time. For the interpretation of the results it is important to determine what the goal is.

By policy goals we mean the vision of the government with respect to the societal contribution of renewable energy technologies. These can be short- or long-term goals for renewable technologies, i.e. PV or wind, or societal themes, i.e. sustainable mobility? The policy goals with respect to renewable energy technologies can be determined along 2 dimensions: 1) environmental/energy goal: contribution to CO2 emission reductions, guaranteed energy supply and reduction of fossil fuel dependency; 2) economic goal: value and contribution of emerging sectors such as renewable energy technologies related to economic growth in and export of the home country. One goal does not exclude the other but they can be different and will have an effect on the evaluation of the functioning of the innovation system. The optimal configuration of an innovation system will then be dependant of the policy goals.

If the policy goal is to obtain economic profit then a lack of the system function market formation does not need to be a problem if the technology is exported but not implemented in the home nation. On the other hand if a large amount of the technology is important to achieve environmental/energy goals a lack of system function knowledge development does not need to form a problem as the goal is achieved. In this step the link needs to be made between the results of the analysis of the structure and the functioning of the ideal TIS. In this step the most important barriers need to be ranked in order to provide recommendations on how to achieve the policy goal.

Finally, an important insight from innovation studies is that there are different relevant spaces for public intervention, since some technological developments require international policies while others are the realm of regional policies. This means that the location of new policy programs and the geography of technological innovation more broadly, is subject to path-dependent dynamics where innovations may prosper in some locations and become marginalized in other locations (Arthur 1994).

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Abstract

The development and diffusion of offshore wind energy technology is important for European energy policy. However, the large potential does not automatically lead to a large share in future energy systems; neither does an emergent stage of technological development automatically lead to success for companies and the related economic growth and growth in employment. Recent insights in innovation studies suggest that the success chances of technological innovations are, to a large extent, determined by how the surrounding system (the innovation system) is built up and how it functions. Many innovation systems are characterized by flaws that hamper the development and diffusion of innovations. These flaws are often labelled as system problems or system challenges. Intelligent innovation policy therefore evaluates how innovation systems are functioning, tries to create insight into the systems' challenges and develops policies accordingly. This report assesses the European offshore wind innovation system based on insights from four countries: Denmark, the UK, the Netherlands and Germany. We use the Technological Innovation System (TIS) approach to analyse the state and functioning of the system at the end of 2011. Based on the analysis we identify four types of systemic challenges: (i) actor-related such as deficiency of engineers; (ii) institutional, e.g. non-aligned national regulatory frameworks; (iii) interaction-related like poor transferability of scientific knowledge to specific contexts of application and; (iv) infrastructural such as poor grid infrastructure. We suggest the challenges require a systemic, coordinated policy effort at a European level if the system is expected to contribute to the goals of climate change reduction and stimulation of green growth.

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