Formation of competences to realise the potential of offshore wind power in the European Union[1]

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Abstract

The electricity sector has to undergo a large-scale transformation process to reduce the threat of climate change. Wind power has a strategic role to play in this process. This paper makes an assessment of the types and numbers of engineers required to sustain a large-scale expansion of offshore wind energy in the EU and draws lessons for universities. A variety of competences are required, including a) deep competences in many fields (electrical, mechanical but also engineering physics and civil engineering); b) integrative competences within engineering (e.g. mechanical and electrical engineering) but also between engineering and non-engineering fields (e.g. meteorology and logistics). A large number of engineers are required. It is estimated that there will be a need for more than 10 000 new engineers from now to 2020. The volume and nature of the competences required raise serious questions for the scale and organisation of training programmes at Universities.

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Keywords: Transformation of the energy sector, Offshore wind power and Competences

1 Introduction

There is strong scientific evidence that emissions of greenhouse gases cause climate change (IPCC 2007). Stern (2006) emphasises that these emissions eventually need to be reduced by about 80 per cent for stabilisation to occur in terms of concentration of CO_2 equivalents at the level of 500 ppm. Much of this reduction needs to have taken place by 2050 and entails an almost complete decarbonisation of electricity generation.[2] A central element in this process is an extensive diffusion of energy technologies based on renewable sources, such as wind and solar power, implying a large-scale transformation of the electricity sector.[3]

Wind power began to be diffused in the early 1980s and is now a well proven technology supplied by a global capital goods industry with substantial resources. It has, thus, developed a solid base on which to rest future growth and has, arguably, a strategic role to play in the emerging transformation of the electricity sector. Hitherto, the installations have been onshore but the offshore market is emerging as a distinct segment. Whilst the diffusion of offshore wind power is still in an initial phase, it is expected to take off in the next decade, much due to investments in British and German waters. The longer term offshore potential is very large. By 2030, the European Wind Energy Association (EWEA 2009b) suggests that the stock of offshore wind turbines may generate 563 TWh/year. This would represent a major contribution to EU's efforts to decarbonise the electricity sector.

For offshore wind power, achieving a growth of this magnitude involves overcoming a number of hurdles. One of these is the timely formation of specialized human capital in adequate quantities.[4] EWEA (2009a) identifies this as one of five main challenges in the development of an offshore wind energy industry. It is also, of course, a vital element in sustaining the competitiveness of the European wind turbine industry. As yet, specialized educational programmes in wind energy are few and very recent and there are no programmes specifically for offshore wind energy. Without access to the required volume and types of competences, a rapid growth of offshore wind power may be delayed or even jeopardised. Managers in the whole value chain for offshore wind power emphasise this in interviews. For instance, as one Manager stressed, although he could not specify the number of engineers required, "the strong message is that many more are needed" (Giese 2010). Another manager said that he may need 3-4 times the current number of engineers in the coming decade (Möller 2010b). The European Wind Energy Technology Platform (TP Wind 2009, pp 39-40) also emphasises the necessity of focusing on the formation of a skilled workforce:[5]

"The wind energy sector is currently facing a shortage of qualified personnel. …education…must deliver a trained workforce with the skills required to develop the industry further. These will range from skilled workers needed to manufacture, build and operate the facilities to graduates who understand the technical, commercial and social context of the industry…The industry is on the cusp of becoming fully commercial, but the necessary engineers, technicians and programmes for development are currently unavailable"

The required work force refers to human capital at all levels, e.g. technicians, engineers and PhDs. The objective of this paper is, however, limited to a) making a preliminary assessment of the types and magnitude of *engineering* competences[6] required to sustain a large-scale expansion of offshore wind energy and to b) drawing lessons for universities.[7] The paper is structured as follows. Section 2 introduces the methodology. Section 3 identifies key obstacles facing the offshore wind industry. Section 4 specifies the types and number of engineers needed while section 5 discusses some implications for universities. Section 6 contains the main conclusions and implications for further research.

2 Methodological challenges

There are two main methodological challenges involved in assessing the types and numbers of engineers required to support a large-scale expansion of offshore wind power. First, an appropriate scenario needs to be chosen. Second, the diffusion depicted in the scenario has to be "translated" into types and numbers of engineers, i.e. these need to be derived from the scenario. Overcoming the second challenge requires insights into the offshore wind energy industry. Much of that insight was generated from interviews (and is presented in section 3). In this section, we recount how the first challenge has been handled and provide information about the interviews. An additional discussion on the method of "translation" is found in section 4.2, which contains an estimate of the number of engineers required.

2.1 The choice of scenario

Decarbonising the power sector implies huge investments in new power capacity. Not only will current fossil fuel based generation need to be replaced but the electricity sector is an expanding one, implying that additional capacity is needed. Between 1973 and 2008, annual global electricity generation grew from 6 100 TWh to 20 200 TWh, i.e. by 3.5 per cent annually (IEA 2010). Assuming a more modest growth rate of 1.6 per cent per year between 2008 and 2050 implies an electricity supply of 39 000 TWh in 2050.[8]

Of the electricity generated in 2008, "low-carbon" sources (renewables and nuclear power) accounted for 6 500 TWh, i.e. one third of total supply (IEA 2010). If all new capacity is to be "low carbon" and current fossil fuel capacity is to be replaced, the added "low carbon" capacity would have to generate about 32 500 TWh/year by 2050. This scale suggests that analyses of future demand for engineers have to use a scenario in which the diffusion of "low carbon" technologies is extensive. The Global Wind Energy Council's (GWEC) and

Greenpeace's (2010) advanced scenario is a case in point. It involves an increase in the supply of wind power from 350 TWh in 2009 to 10 400 TWh in 2050, accounting for about 25 per cent of global consumption.[9] Achieving this growth in supply implies an increase in the annual installed capacity from about 38 GW in 2009 to about 185 GW by 2030, see Figure 1.[10]

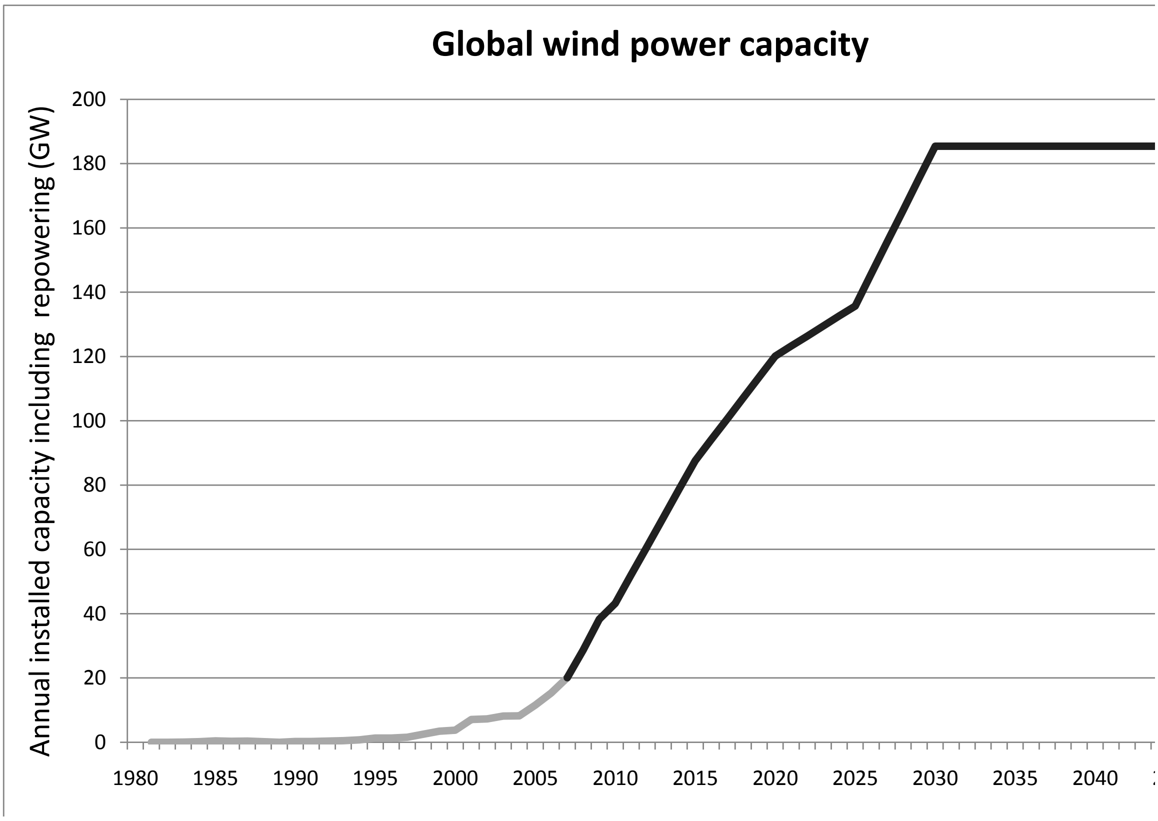

Figure 1 Global annually installed capacity, advanced scenario by GWEC and Greenpeace (2010)

In the European Union (27), gross electricity production amounted to 3 400 TWh in 2008, up from 2 800 TWh in 1997, implying a growth rate of 1.6 per cent per annum (IEA 2010). Electricity generated from renewable energy sources (and waste) and by nuclear power stations came to 520 and 940 TWh respectively (elaboration on IEA, 2011). Assuming a consumption of 5 100 TWh[11] by 2050, constant supply of nuclear power and a full replacement of fossil fuels[12] implies a need for an added capacity of "low carbon" technologies that generate about 3 600 TWh. Clearly, the challenge is also substantial for Europe. Meeting this challenge requires, arguably, a large expansion of wind power but even an extensive diffusion will only solve part of the problem.

In the EU, wind turbines generated 119 TWh in 2008, equivalent to 4 per cent of the electricity supply (IEA, 2011). In another advanced scenario, by EWEA, stretching to 2030, wind power supply increases to 582 TWh in 2020 and to 1 155 TWh by 2030. This would mean that wind power's share of electricity consumption would reach about 30 per cent, i.e. the diffusion would be quite extensive in just twenty years from now (EWEA 2009b). Investment in onshore wind power is projected to reach a peak in 2020 whereas investment in offshore wind power continues to rise over the next twenty years, see Figure 2. By 2027, the annual installed capacity in offshore turbines supersedes that of onshore in Europe (12.5 GW, from 0.6 GW in 2009, see EWEA 2010a) and by 2030, the stock of offshore wind turbines may generate 563 TWh/year, nearly as much as the estimated 592 TWh/year from onshore plants in Europe.

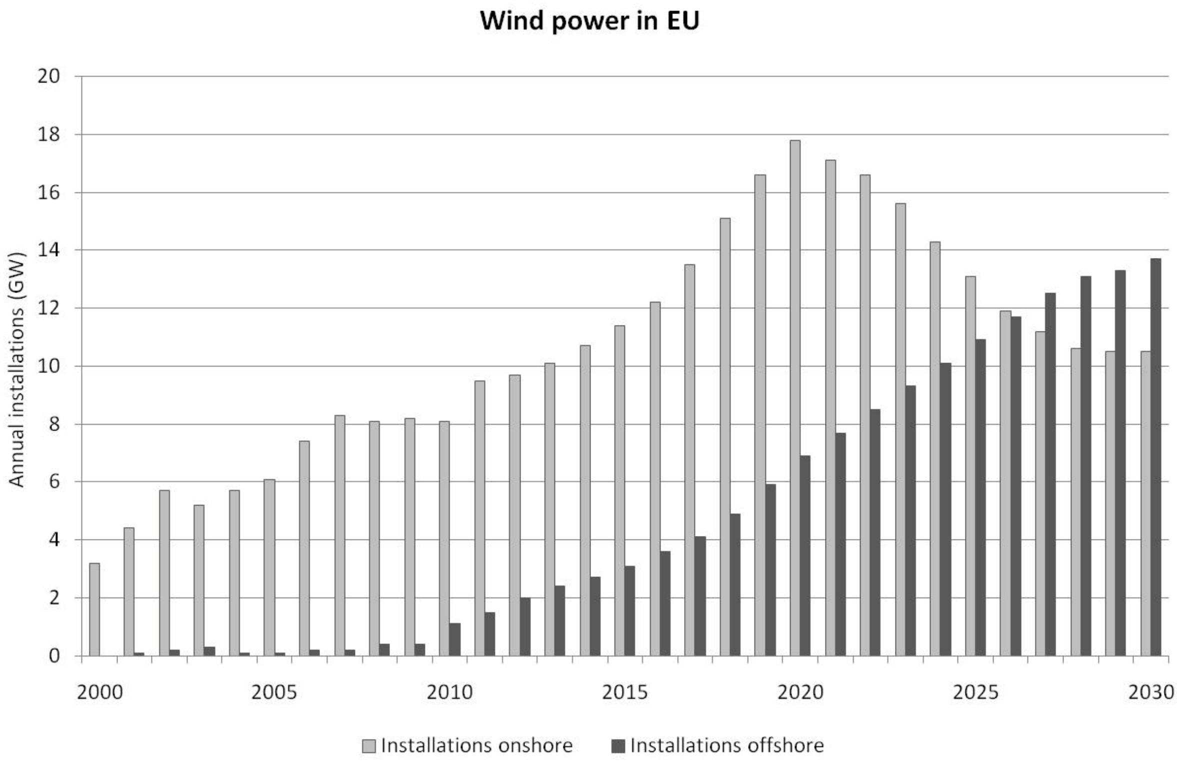

Figure 2 Annual installations of wind turbines onshore and offshore in Europe (EWEA 2009a)

563 TWh would constitute a significant contribution to EU's efforts to decarbonise the power sector. An expansion of offshore wind power is therefore, not surprisingly, seen as of strategic importance to the EU: "...the potential exploitable by 2020 is likely to be some 30-40 times the current installed capacity, and in the 2030 time horizon it could be...some 575 TWh" (European Commission 2008, p. 3). Indeed, over the next twenty years, offshore wind power will, arguably, be a vital element in the "Roadmap to a low carbon economy in 2050" (European Commission, 2011) in which the electricity sector is expected to reduce GHG emissions with up to 68 percent (as compared with 1990) already by 2030. [13] For this reason, we use EWEA's advanced scenario in our analysis.

2.2 Interview based material for "translation"

The main industrial actors in the offshore wind industry are manufacturers of components,[14] turbine manufacturers, producers of power grids and utilities. A wide range of consultancy firms as well as Universities and Institutes have close connections to these actors, see Figure 3.

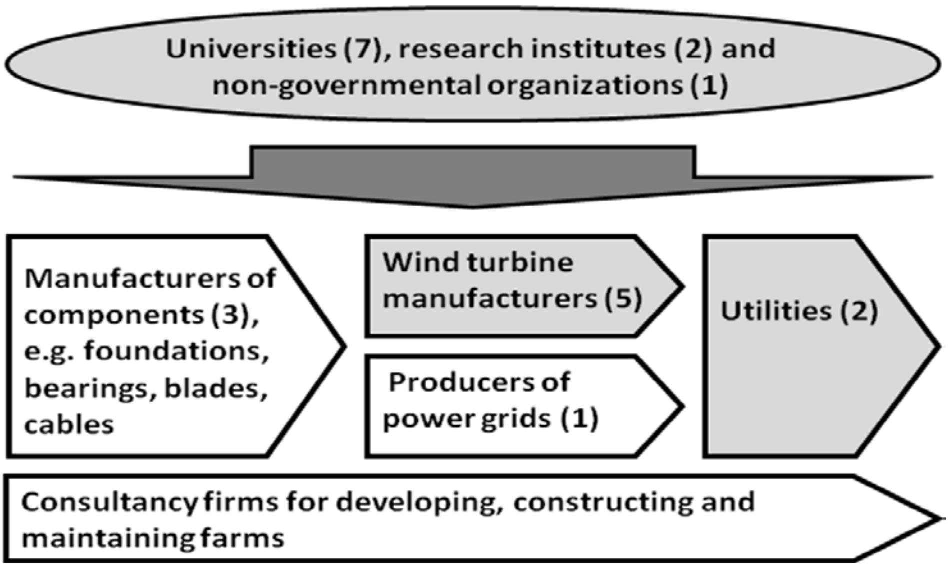

Figure 3 The value chain for offshore wind power. (The number of interviews conducted in each category is indicated in parenthesis)

The analysis is informed by a total of twenty-one interviews in Denmark, Germany, Sweden and the Netherlands. The bulk of the interviews were carried out in Germany and Denmark as they house most of the wind turbine industry. The unit of analysis is, though, European offshore wind energy.[15]

The interviewees are senior members of their organisations. In industry, they include managers in charge of product development in the turbine manufacturers and managers of the offshore market segment in the utilities. In Universities and Institutes, they include

Professors, Directors of Educational Programmes and Heads of Institutes (see References for the names and positions of the interviewees). The interviews lasted for up to two hours and all but one were face to face. We followed a semi-structured interview guide which allowed for a great deal of discussion. The interview guide differed, of course, depending on the organizational affiliation of the interviewee.[16]

The interviews with managers informed us on several issues. First, firm specific data on the number of engineers employed were shared with us. Second, we were given first-hand knowledge of the perceived technical challenges for offshore wind power. This informed us of the need for different types of competences as well as of the number of engineers needed. Third, other factors influencing the future need for engineers were identified. Fourth, in the discussions, it became clear how uncertain estimates are. Hence, the quantitative analyses provided in section 4 should only be seen as providing an indication of the magnitude involved.[17] Given this uncertainty, we limited the time horizon, and consequently our estimates, to 2020 for the simple reason that the interviewees were not able or willing to extend the time horizon further – as one Manager put it "After 2015, it is more like looking into a crystal ball". The starting point for our analysis is, thus, the estimated diffusion until 2020, when the annual installed capacity reaches 6.9 GW in the EU offshore market (and 17.8 GW in the onshore market).

From representatives of Universities and Institutes, we gained additional insights into the technical challenges involved in an expansion of offshore wind power. We also learned of current educational programmes and how future programmes may be organised.

3 Obstacles for realising the potential of offshore wind power

As mentioned above, "translating" an estimated diffusion to demand for engineers (both types and numbers) requires an understanding of the characteristics of the industry. In such a "translation", it is vital to appreciate that the offshore wind power segment has features that differ greatly from the onshore segment. First, the scale of investment is much higher – a wind farm may cost 1 billion Euros or more, involving a large number of turbines (Giese 2010).[18] This means that the customers are larger utilities and not individual farmers or cooperatives. Second, the harsh environment means that the onshore turbines either need to be modified or replaced by specially designed offshore turbines (van Bussel 2010). Third, the higher costs of installing turbines means it makes sense to build larger turbines – indeed, several firms, such as Repower, Bard and Multibrid, have developed 5 MW turbines and are developing even larger turbines.[19] Fourth, as the transportation of components, such as nacelles and blades, is very difficult due to their size, firms are setting up manufacturing facilities in harbours, which need to have an adequate infrastructure. Specialised vessels are also needed to ship and install the turbines. Developing the offshore segment is, thus, not a simple diversification by the wind turbine industry into a new segment. Indeed, there are many obstacles to more extensive diffusion offshore.[20] In what follows, we will identify three of these, all of which have a bearing on the need for specialised human capital. Particular emphasis is given to a set of technical challenges.

3.1 Infrastructure and institutional alignment

Infrastructural investment lags behind. One of the main obstacles is limited transmission capacity to offshore sites as well as an associated lack of integration of offshore wind capacity into the European grid system. As the offshore grid cannot be isolated from the rest of the grid (Bak-Jensen 2010; EWEA 2009a), the onshore grid capacity across Europe needs to be enhanced as well (TPWind 2008). This need is further driven by the formation of an EU market for electricity, and an associated increase in trade. In the coming ten years, Normark (2009) estimates that grid investment will need to be three to four times larger than in the past decade. Other infrastructural bottlenecks are a lack of vessels for transporting and installing offshore turbines, the supply of substructures as well as shortages in adapted ports for supplying the offshore market (EWEA 2009a; Giese 2010).

Institutions (in the sense of regulations, norms and values) are not aligned to offshore wind energy. The misalignment refers to uncertainties in the funding of grid connections to transformer stations (Wagner 2010)[21] as well as to differences in regulations and market mechanisms between member states which hamper an efficient combination of trade and offshore wind power transmission via a transnational grid (EWEA 2009a).[22] The misalignment also refers to a lack of integrated maritime planning in many states (European Commission 2008; EWEA 2009a).[23] Different industries (e.g. fishing, oil and gas, shipping) compete over space, and environmental concerns put additional items on the agenda. The various activities are regulated by different agencies which lead to fragmented policy making and very little EU coordination (EWEA 2009a). Only a few European countries have dedicated offshore wind areas.[24] Finally, the legitimacy of wind power continues to be questioned (Ross and Kölling 2010). Wind power still competes in the eyes of investors and politicians with other technologies, in particular nuclear power and Carbon Capture and Storage technologies.

3.2 Technical challenges

The wind turbine industry is still a young industry.[25] Firms face many technical challenges and extensive efforts in research and development are needed to meet these. The challenges are especially large for offshore wind turbines. Our perception of an industry where the technology will change a lot in the course of its continued diffusion, rather than of a mature industry standardising their products, is vital for our "translation" work in which we derive the types of engineering competences and number of engineers needed.[26] In what follows, we will outline the most demanding technical challenges for offshore wind energy.

3.2.1 Design of offshore wind turbines

Although wind turbines can benefit from thirty years of development work for onshore applications, there are many technical challenges for offshore deployment. First, the turbines must operate in the harsh environment that prevails at sea, being exposed to water, wind, salt and sun during their entire lifetime of approximately 20 years (Huhn 2010). This implies that issues such as corrosion, surface protection and condition monitoring need to be dealt with. The harsh environment also means that the turbines must be designed with due consideration to health and safety features for the personnel (Normark 2009) and to be operated with a minimum of maintenance (Karlsson 2009).[27] As EWEA (2009a, p. 48) explains:

"The larger the machine and further away from the coast, the larger the economic loss for non-operation and associated maintenance....Modern wind turbines...need a number of major overhauls during their lifetimes to ensure efficient operation...Wind turbines are currently designed in such a way that the exchange of main components or subassemblies is difficult. More efficient and newer drive train concepts are needed to bring turbine reliability to the required level. A more modular build up of drive trains with more built in redundancy could help faster, cheaper and more efficient turbine maintenance."

Second, there are challenges concerning electrical components, such as power converters and generators.[28] Direct-drive offshore turbines are now emerging which means a reduction in the number of moving parts (by excluding the gearbox). Yet, the generators in such turbines are heavy and a challenge is to develop new and lightweight generators (Barth and

Kärn 2010; EWEA 2009a; TP Wind 2008). In terms of grid connections, the emerging standard of HVDC (high voltage direct current) is a big challenge for the turbine suppliers (Quell 2010). General Electric, for instance, has access to a large test station where variations in the grid voltage, frequency and amplitude can be analysed in terms of their impact on wind turbines (Carlson 2010).[29]

Third, control systems must be further developed for the complex technical system of an offshore wind turbine. It is necessary to optimize the balance between performance, loading and lifetime which involves e.g. reducing the mechanical loads on the wind turbine structure and integrating control systems with maintenance strategies (TPWind 2008).[30] Indeed, one of the major offshore wind turbine manufacturers, Repower, has a large department working with software for the control system which allows for monitoring, controlling and communicating with the turbine (the latter specified by the utilities) (Quell 2010).

Fourth, in the last two decades, technical development has been dominated by up-scaling of turbines. The turbine size has increased by a factor of 20 and rotor diameter has grown from 15 meters to 160 meters (EWEA 2010b). The size of the turbines continues to grow. Whereas onshore turbines are not normally larger than 2-3 MW, 6 MW offshore turbines have already been developed and the scaling up may eventually lead to turbines with an effect of 10-20 MW (EWEA 2009a). This up-scaling process involves development efforts for each component e.g. designing rotor blades must take aspects into consideration that are not important for smaller turbines (TP Wind, 2008). Equally important, the constituent elements of the technical system must interact in a manner that ensures a dynamic stability, which is of particular importance for the offshore segment (Nörker Sörensen 2010). Mechanical engineers, thus, have to undertake advanced calculations of the behaviour of not only rotor blades[31] (and other components such as cast iron components) but also of the entire turbine structure in which loads from wind and sea are integrated with those of foundations, generators, transformers etc. (Carlson 2009; Ross and Kölling 2010). Load calculations, involving simulations with large data sets, have to be made in order to improve materials and turbine components, ensure dynamic stability and reduce costs (Arndt 2010; Nörker Sörensen 2010; TPWind 2008). [32]

3.2.2 Foundations

Offshore turbines require completely different support structures than onshore turbines. There are, however, no standard offshore foundations and the type varies with water depth (EWEA, 2009a). Early experiments are being made with floating foundations for deep water applications which are found off the Norwegian coast, the Atlantic Ocean and in the Mediterranean (EWEA, 2009a). The foundations need to be protected from corrosion, especially in the splashing zones (Huhn 2010). A better understanding of soil structures, and their interaction with the turbine[33] and its foundation, is needed in order to prevent the occurrence of scour[34] and to be able to construct stable foundations (Barth and Kärn 2010).

3.2.3 Meteorology

Offshore meteorological conditions differ from onshore conditions and some processes are specific for offshore, such as the wind/wave/current interaction (TPWind 2008). There is, however, insufficient understanding of meteorological conditions offshore. This means that it is not possible to a) fully adjust the turbine design to offshore wind conditions, b) provide short-term forecasting of these or c) optimize the layout of the wind farm. The European Wind Energy Technology Platform (TPWind 2008) identifies *Wind conditions,* including siting of wind turbines and wakes[35] in and between wind farms, as one of its four strategic research areas (TPWind 2008). Indeed, several prominent research organisations have on-going projects on meteorology and wind power, for example the Danish research institute Risø and the German ForWind (Universities of Oldenburg, Hannover and Bremen).

To increase knowledge of meteorological conditions, tools for data collection, measurement, simulation and optimization have been developed, but still more sophisticated methods are needed. Remote sensing techniques, like Lidar, must be further developed for measurements of the speed and direction of winds (Barth and Kärn 2010; Hauge Madsen and Larsen 2010).[36] Computational fluid dynamics models are being developed for more advanced simulations of rotor and wind park aerodynamics (Barth and Kärn 2010).

3.2.4 Grid integration

As mentioned above, a rapid diffusion of offshore wind turbines will require extensive efforts to integrate wind power into the electric grid, both onshore and offshore. The high voltage infrastructure for the offshore wind site and the connection onshore have to be calculated (Ström Madsen 2010) and the whole power system designed to ensure a high grid stability and power quality (Bak-Jensen 2010; Ross and Kölling 2010; TPWind 2008). The large-scale integration of wind power in the electricity system that comes with an expansion of offshore wind power is another challenge (Nörker Sörensen 2010). To facilitate the integration, wind power plants must in some aspects have the character of a conventional power plant, for example regarding control, stability and predictability of power generation (Bak-Jensen 2010; Hauge Madsen and Larsen 2010; TPWind 2008).

4 An assessment of the types and numbers of engineers needed

There are, thus, a number of infrastructural, institutional and technical obstacles to a rapid deployment of offshore wind turbines. In this section, we will use this contextual knowledge to help us "translate" the figures in the chosen scenario to a demand for types and numbers of engineers. We will begin with identifying the range of competences needed and then proceed to discuss the number of engineers.

4.1 Types of engineering competences for offshore wind power

The specified challenges will have to be met by the deployment of a wide range of engineering competences, conducting numerous tasks for different actors. The challenges and the associated competences are summarized in Figure 4. The required competences are both *deep* competences within a knowledge field and *integrated* competences that combine two or more knowledge fields that are normally taught separately.[37]

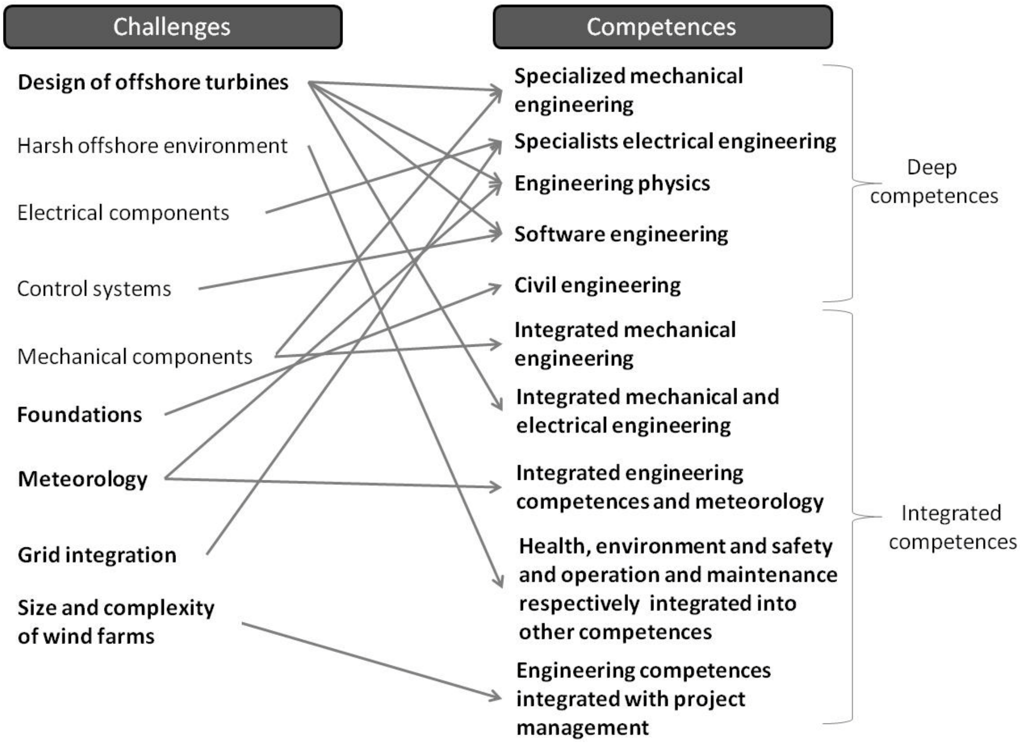

Figure 4 Challenges and competences for offshore wind power. (The arrows indicate how the competences are derived from the listed technical challenges)

4.1.1 Deep competences

Specialists with a deep understanding are needed in numerous knowledge fields, including mechanical engineering, electrical engineering, engineering physics, software and civil engineering. Skilled *mechanical* and *electrical* engineers are needed for the development of components such as gearboxes, bearings, generators and frequency converters (Ross and Kölling 2010). Designing turbines and offshore wind farms requires *mechanical engineers* to calculate fatigue loads on components, interactions of load structures for turbines and foundations, and aerodynamics of the whole wind farm (Arndt 2010; Carlson 2009; Huhn 2010). *Electrical engineers* are needed for the integration of large offshore wind farms in the power grid (Bak-Jensen 2010). As wind farms grow in size, there is an increased need for such electrical engineers to work with the stability of the grid and control in order to balance the power output from the farm with market demands (Bak-Jensen 2010; Carlson 2009).

Additionally, *software engineering* competence is required for handling the growing grid and for developing software for control systems (Normark 2009; Quell 2010). *Engineering physicists* are needed for calculating the influence of turbulence on, for example, blades and nacelles, and for increasing the understanding of meteorological conditions (Barth and Kärn 2010). Finally, since offshore turbines require a completely different support structure and foundations, *civil engineers* specialized in offshore constructions are necessary (Huhn 2010; Ström Madsen 2010).

4.1.2 Integrated competences

Three categories of integrated competences can be identified; a) integration of specialist competences within the same field of engineering, b) integrated competences from different fields of engineering and c) integration of engineering competences and competences from fields that are not typically taught in engineering programmes, including management and meteorology.

The first category includes integrations *within* mechanical engineering. For development of rotor blades, mechanical engineers with integrated competences in material sciences, fluid dynamics and process engineering would be the ultimate background (Månsson 2010; Nörker Sörensen 2010; Ross and Kölling 2010).[38]

In the second category, we find engineers who combine electrical and mechanical engineering. An integrative competence would be ideal for design of wind turbines, as articulated by many industrial actors (Huhn 2010; van Bussel 2010). Hence, there is a need for engineers who understand wind turbines as a whole, including e.g. aerodynamics, lightweight constructions, gearboxes and have the ability to optimise designs, bearing in mind the various loads (Carlson 2009; Nörker Sörensen 2010; Seifert and Kühne 2010). They may not need to be competent in designing a gearbox but they should be able to determine the exact load for the gearbox and relate it to the rest of the components in the wind turbine (Seifert and Kühne 2010). Engineers with this integrative competence are currently few, work as product development managers and have developed their competence on the job (Arndt 2010; Quell 2010; Ross and Kölling 2010).[39]

The third category involves integrating engineering knowledge with non-engineering disciplines, such as meteorology and management. Three such combinations may be identified. First, offshore meteorology needs to be combined with electrical, mechanical or other engineering fields for the design of offshore turbines and wind farms (Ross and Kölling 2010). For the development of more reliable wind farm simulation models, which for example take wake effects into account, engineers with a background in engineering physics and software are needed (Barth and Kärn 2010; Huhn 2010; Normark 2009; Quell 2010).

Second, as pointed out above, given the harsh offshore environment, the need for maintenance has to be minimized. This implies that the turbine, and all its components, needs to be designed accordingly. Maintenance aspects need, therefore, to be integrated into all design processes (Karlsson 2009). Much the same can be said about health, environmental and safety aspects (Feld 2010).

Third, with their understanding of technical issues engineers are suitable project managers handling extremely complex projects worth as much as 1 billion Euro. Project management tasks may relate to all the challenges in Figure 4. In addition, they may involve dealing with logistics, marine engineering, health and safety and maintenance (Giese 2010). Project managers may also require knowledge of finance, risk management, communication, understanding of certification bodies, approval processes and insurance (Cooke et al 2010; Feld 2010; Giese 2010; Hoymeyer 2010; Huhn 2010).[40] A broad understanding may also help in tackling the institutional obstacles outlined above, including influencing the policy framework (Hohmeyer 2010).

In sum, to meet the challenges facing offshore wind energy, a broad range of engineering competences needs to be developed, including competences that combine knowledge fields in novel ways.

4.2 The order of magnitude of engineers needed

This section discusses the order of magnitude of the need for engineers to realise the potential of offshore wind power, bearing in mind that onshore wind is still expanding. Our estimates are based on the scenario for diffusion of wind power presented in section 2 (EWEA 2009b), limiting our time horizon to 2020 when the annual installation is estimated to be 6.9 GW for offshore and 17.8 GW for onshore. Our focus is on wind turbine manufacturers and utilities. As the value chain is much larger, see Figure 3, our estimates are cautious. To partly address this problem, we end the section with two illustrative examples from manufacturers of components and power grids.

4.2.1 The number of engineers needed by wind turbine manufacturers

The estimates of the number of engineers needed by wind turbine manufacturers include engineers working with both onshore and offshore wind since a) firms were not willing, or able to specify the number of engineers working in each of the two segments; b) engineers can shift between the two segments (although not necessarily without problems) so it is the combined demand for engineers that needs to be satisfied unless one segment is to expand at the expense of the other. Hence, our estimate provides an answer to the following question: How many additional engineers are required to deliver the expected supply in the European market in 2020?

Data on the number of engineers employed has been collected for firms covering more than 90 per cent of the installations offshore in Europe in 2009 (EWEA 2010a) and for a sizeable share of onshore installations. Setting the combined output (in 2009) of these firms in relation to the stock of engineers leads to an average output of 2.3 MW per engineer.[41] We use this ratio[42] to derive the demand for engineers from the estimated growth in supply from 8.6 GW in 2009 to 24.8 GW in 2020, i.e. by 16.2 GW.

In our estimate, we assume therefore that the ratio of MW per engineer is constant over the period studied, i.e. that learning effects are balanced by an increased demand for engineering inputs. This assumption is informed by perceptions of senior managers, e.g. Quell (2010) and Ström Madsen (2010) and by our understanding of the technical challenges facing wind power (section 3.2). R&D efforts are, however, also expected to rise for other reasons. In particular, the width of the product range is expected to increase and costs have to decrease, requiring substantial engineering efforts (Quell 2010). Although more engineering efforts are needed offshore than onshore (Quell 2010), the latter still requires much engineering input. As for offshore, onshore turbines need to be adjusted to specific sites and customer demands (Quell 2010). Moreover, while the focus for the last two decades has been on up-scaling, challenges related to e.g. improved designs, volume manufacturing and standardization remain to be solved (Hauge Madsen and Larsen 2010). Finally, there are local requirements regarding e.g. grid regulations and health and safety, in each country which necessitates adjustments.[43]

Applying the ratio of output per engineer (2.3 MW) to the estimated increase in annual installed capacity (16 200 MW) in 2020 implies a need for an additional 7 000 engineers.[44] Of course, this figure is sensitive to the assumption of a fixed MW/engineer ratio. EWEA (2009b, Annex 3 and 5) assumes that the capital investment per GW falls from 1.26 billion Euro in 2009 to 0.95 billion in 2020. If the same reduction were to apply to engineering input, the need for additional engineers would be reduced to 5 300. The demand for engineers is, however, also sensitive to global market development, see Figure 1. As European wind turbine manufacturers internationalize production of turbines to Asia and the US, much of the product development and engineering support for manufacturing is likely to move closer to the market but core research and design is expected to remain in Europe (Ström Madsen 2010). Production abroad will, thus, constitute an additional source of demand for engineers (i.e. additional to the expected increase in demand in the EU market). Hence, 7 000 engineers may well be the correct order of magnitude.[45]

4.2.2 The number of engineers needed in utilities

For utilities, the estimate is limited to the offshore segment. Data was collected from two utilities operating in the North Sea, which together installed more than 55 per cent of the capacity in the North Sea in 2009 (EWEA 2010a). How many engineers that are needed by the utilities depend on their degree of vertical integration; some utilities buy turnkey solutions while others have the competence to perform most activities for the development of an offshore wind farm, except designing the turbine (Feld 2010). The two interviewed utilities have different strategies, one is vertically integrated to a large extent while the other relies more on consultants for engineering competences.

For these two utilities, the estimates are based on a) the planned total installed effect in the period 2010-2020 and b) the required number of engineers for achieving this output.[46] Hence, we simply asked the utilities how many engineers they require to achieve their targets. Data from the two utilities were then merged into a figure of 14.3 MW per engineer. This ratio was then applied to the estimated total installed effect in the period, according to EWEA (2009b). Hence, we assume that the two utilities are, taken jointly, broadly representative of the combined set of utilities operating in the North Sea.[47]

According to the EWEA (2009b), the total installed effect offshore was 1.9 GW by 2009 and by 2020 this is estimated to be 40 GW. Hence, an additional 38.1 GW is estimated to be installed in the period studied. If this is divided by 14.3 MW (estimated output per engineer) and the number of engineers currently employed is subtracted, it would lead to a need for 2 000 additional engineers until 2020.

The real number is, however, considerably larger since the ratio used in this calculation only takes into account in-house engineers at the utilities. Consultancy firms assist utilities with a wide range of activities (see Figure 3). Indeed, one utility has about as many engineers from consultancy firms as in-house involved in their offshore projects (Möller 2010b).

4.2.3 The magnitude of engineers needed in other parts of the value chain

The previous estimates cover only parts of the value chain, see Figure 3. Component suppliers have not been included and, in addition, more engineers are required for the design and manufacturing of installation vessels, foundations, cranes and for enlarging the electrical grid (Ström Madsen 2010). The need for engineers in other parts of the value chain will be illustrated by two examples.[48] First, suppliers of power grids will require many engineers for the expansion of transmission capacity (see section 3.1). The output per engineer (in MW transmission capacity per year) can be scaled up more easily than in turbine manufacturing (Normark 2009). Still, increasing the annual installed capacity threefold, from 8.6 GW per year in 2009 to 24.8 in 2020, may require almost a doubling of the number of engineers needed in the suppliers of power grids (Normark 2009).[49]

The second example is from one of the main global manufacturers of bearings, sealing and lubrication systems, where the number of engineers is strongly linked to the number of turbine models (Karlsson 2009). These engineers have a heavy workload due to an expanded product portfolio that accompanies the rapid diffusion of wind power. For each model, these application engineers need to interact a great deal with the customer to make sure that the bearings, gearbox and generator function well together. Depending on the future number of models, such engineers may need to be quadrupled to satisfy the demand in the scenario for 2020 (Karlsson 2009).[50]

In sum, the number of engineers that will be required by turbine manufacturers and utilities is estimated to be around 9 000. Two examples from other parts of the value chain suggest that scaling up of the engineering workforce is also to be expected by other actors in the value chain. We suggest, therefore, that the total number of new engineers needed may easily exceed 10 000.

5 Implications for universities

Industry recruits, of course, staff from a range of related industries. For instance, aerodynamics engineers may be recruited from the automobile industry (Ross and Kölling 2010) and material science specialists (for blades) from the shipbuilding industry (Giese 2010). Yet, as industry expands in line with the scenarios mentioned in section 2, arguably, the particular needs of the wind energy industry should be reflected in the programmes and curricula at the Universities. A central task for Universities is, therefore, to ensure that competences are built in appropriate variety and volume and done so in a timely fashion.

In the countries around the North Sea, there are a handful of dedicated wind energy MSc programmes (Copenhagen, Aalborg, Bremerhaven and Flensburg).[51] None of these programmes are dedicated to offshore although the curricula are influenced by the particular features of that segment. The programmes have quite different profiles. The Flensburg and Bremerhaven programmes are broad and integrative. The former focus on industrial engineering, i.e. it is management oriented, including project management (Hoymeyer 2010), whereas the latter has an applied integrative technical profile, very much oriented towards the offshore segment (Seifert and Kühne 2010). The Copenhagen programme educates specialists with deep knowledge in either electrical or mechanical engineering for the R&D departments in the wind turbine industry (Nörker Sörensen 2010). Finally, in Aalborg the programme is restricted to electrical engineering, dealing e.g. with the large-scale integration of wind power in the grid, and coexists with two other MSc programmes in electrical engineering where the graduates go to turbine manufacturers or utilities (Bak-Jensen 2010). All in all, these three programmes in Aalborg enrol about 40 MSc students whereas the Copenhagen programme accepts 30 students. In Bremerhaven, 15 students are recruited whilst Flensburg enrols 12 students annually.

New programmes are in the pipeline in Oldenburg, Hannover, Aarhus and Delft. In Delft, the University's Wind Energy Research Institute (DUWind) plans to start a MSc programme in Wind Energy which integrates courses in mechanical and electrical engineering (van Bussel 2010). In Hannover, the University will start a programme in Wind Energy Engineering (Kärn 2011). There are also instances in which students follow either a broader programme (e.g. in renewable energy, sustainable energy technology) or a highly focused one (e.g. Aerodynamics in Delft and Physics as well as Engineering Physics in Oldenburg) in which they may specialise in wind energy or wind physics. At TU Delft, it is also possible to study specific courses for offshore wind, e.g. offshore technical support and offshore wind farm design (van Bussel 2010). These pioneering programmes need to be supplemented with many others if industry is not to suffer unduly from a shortage of competences over the next decades. In what follows, we will discuss how Universities may act to avoid the occurrence of such shortages.

First, more programmes for developing *deep competences* are required. Conventionally, it is either electrical or mechanical engineers who work in turbine manufacturers, component (including grid) suppliers and utilities. The main bottleneck in terms of competence is, indeed, a shortage of electrical engineers (e.g. Arndt 2010; Bak-Jensen 2010; Hohmeyer

2010; Normark 2009). These are required to a) strengthen the onshore grid and build an offshore grid and b) facilitate a large-scale integration of wind power into the power system. They are also needed by turbine manufacturer, utilities and some component suppliers.

As was plain in section 3, the technical challenges facing the wind energy industry demands that deep competences from other disciplines than mechanical and electrical engineering are formed. These include physics, meteorology, civil and software engineering. Indeed, the coming programmes in Oldenburg and Hannover may be examples of such a broadening of the knowledge base. For the offshore segment, it is vital that programmes are formed which provide an opportunity for new types of deep competences to be formed.

However, these specialists need to be able to understand and communicate with engineers with other competences. A programme for this could, perhaps, be structured as follows; engineers with BScs in appropriate disciplines would be recruited into a MSc programme in which they start with an introduction to the whole technical system of a wind turbine. This part may be more or less ambitious but should aim at gaining an understanding of the context in which deep competences are applied, including an ability to communicate across disciplines (Hauge Madsen and Larsen 2010). For the rest of the programme, the students may choose different specializations, e.g. in materials and blades, drive trains, control engineering, interaction between the environment and load structures, etc (Huhn 2010).

Second, *integrative competences* need to be developed to a greater extent. As was elaborated on in section 3, this refers to a number of different possible combinations. For instance, a deep knowledge in “Physics of the wind” may be combined with other engineering competences in order to improve the designs of offshore wind turbines.[52]

A perhaps more challenging task is to integrate electrical and mechanical engineering (Nörker Sörensen 2010). Whilst an integrative competence may come out of broader programmes, gaining both a deep and integrative competence in two years is a daunting task,[53] requiring that students are excellent in e.g. mathematics and programming and that a resistance to cross-disciplinary work is overcome (Hauge Madsen and Larsen 2010; Nörker Sörensen 2010). At the University level, such programmes do not exist at the MSc level, neither in Denmark, nor in Germany (Huhn 2010).[54]

However, in Copenhagen, this is now done at the PhD level (Nörker Sörensen 2010). Indeed, integrative competences that cut across broader disciplinary fields may require more than two years. An option may then be to organise a continued educational programme, offering options of gaining deep competence in, say, aerodynamics, meteorology or drive trains that supplement the competence gained in broader MSc programmes (Seifert and Kühne 2010).

Third, a dedicated MSc programme in *offshore project management* is required.[55] This is a vital competence among both turbine manufacturers and utilities (Möller 2010a). Managing large and extremely complex projects requires competences in a wide range of fields (Larsen and Hauge Madsen 2010). These include an understanding of the various technical components but also of logistics, meteorology, maintenance (Giese 2010), risk management (Möller 2010a) and communication (Cooke et al. 2010).

Expanding the number and types of programmes raises a number of issues for the Universities. We will mention two of these.[56] First, scaling up of the formation of competences implies an increased need for teachers/researchers to design and implement the programmes. As advanced teaching rests on research, more funding is, presumably, required for wind energy related research. However, it is also vital that this research is organizationally linked to PhD and MSc educations, i.e. researchers teach at different levels.[57] It is in this light that we can interpret the recent integration of the Danish Institute Risö and the German Fraunhofer Institute in Bremerhaven into the educational programmes of Universities (Barth and Kärn 2010; Hauge Madsen and Larsen 2010; Vindmölleindustrien 2000).[58]

Second, with a few exceptions (e.g. DTU and Risö in Copenhagen), Universities and Polytechnics (roughly Fachhochschule in Germany), do not have a research base which is large enough to offer many types of specialization. Offering a broad MSc programme as well as options for gaining deeper competence in selective fields would, therefore, be limited to a few Universities. This raises the possibility of organizing a European portfolio of specialized courses that are organizationally integrated and made easily available to students from Universities taking part in the programme.

The students from, say, Bremerhaven with its broad programme, may choose to specialize in aerodynamics, taking courses in Bremen (Seifert and Kühne 2010). Another case would be if mechanical engineering students from Chalmers University of Technology in Sweden (with no wind energy programme so far) could choose wind energy as an application field in the second year at the MSc level. Such a student could then study gearbox design in Aachen, how that component interacts with other mechanical elements (perhaps in Copenhagen) as well as how maintenance can be minimized in the design process (Karlsson 2009). Of course, setting up such an organizational structure requires that Universities and Institutes see each others not only as competitors but also as partners and that the funding arrangements are such that it makes sense to provide courses (Hauge Madsen and Larsen 2010).[59]

6 Conclusions and some implications for further research

Decarbonising the electricity sector involves a very large-scale industrial transformation in which a huge “low carbon” capacity needs to be built in the course of the next decades. In that process, on and offshore wind power is likely to play an important role. The objective of this paper was, therefore, to a) make a preliminary assessment of the types and magnitude of engineering competences required to sustain a large-scale expansion of offshore wind energy and to b) draw lessons for Universities that wish to respond to this challenge.

To meet a set of technical and other challenges for offshore wind energy, a broad range of engineering competences need to be developed, including competences that combine knowledge fields in novel ways. The challenge is, however, not only to generate a rich variety of competences but also to make sure that a large number of engineers are available on the labour market. Whereas our estimates are limited in scope and precision, the order of magnitude of additional engineers required is likely to exceed 10 000 over the next decade. This number includes (some of the) engineers needed to sustain a continued diffusion of onshore wind turbines in Europe.

The variety and volume of competences required has serious implications for Universities. Whereas industry will be expected to continue to source a great deal of its competence from related industries, an industrial transformation of this type would be facilitated by an expansion in the number and types of educational programmes at Universities. More programmes are required to generate deep competences in a range of engineering fields where there are great opportunities to design novel programmes in not only electrical and mechanical engineering but also in other fields, such as civil engineering and engineering physics. More programmes are also needed in which various fields are integrated, both within engineering and with other fields, such as meteorology and management. The latter includes specialised project management programmes in offshore wind power.[60]

Expanding the number and types of programmes requires, of course, that the teaching staff is enlarged and, if teaching is to be linked to research, an expansion in R&D funding. It may also require that a European portfolio of specialized courses is organizationally integrated and made easily available to students from Universities taking part in the programme. Designing novel programmes, enlarging the associated teaching staff and making a rich menu of specialized courses available at the European level are, therefore, critical challenges for the European Universities.

As for further research, we suggest that there are, at least, three lines worth pursuing. First, in the case of wind power, a greater coverage of the value chain would be useful. Second, wind power is only part of a future “low carbon” power system. The same issues are, therefore, to be expected to be valid for a range of other “low carbon” technologies. Indeed, a shortage of competences has already been seen in the field of Carbon Capture and Storage (van Alphen 2011). It would, therefore, be useful to conduct a study where the coverage is the transformation of the entire power system and what implications this has for the Universities in terms of the composition of educational programmes. Third, as shortages emerge, advocates of various technologies, including nuclear, are likely to compete for influence over the research and educational policies of Governments as well as over the policy of Universities in terms of their educational programmes. This political process, including how various industries and other advocates articulate the need for new competences, deserves attention.

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[1] We gratefully acknowledge funding by the Swedish Energy Agency, the EU 'Power Cluster' project and West Gothia Region in Sweden. 21 interviewees kindly shared their experiences and insights with us (see sources). Florian Kern, Björn Sandén and Adrian Smith gave us many constructive comments on an earlier draft. Any remaining errors are ours.

[2] If policies are set to limit emissions of greenhouse gases to 450 ppm of CO_{2eq}, making the energy system consistent with a 2^{o} C target, it would imply a power sector which is largely decarbonised, particularly in developed countries (IEA 2010).

[3] There are also other drivers of a change in this direction, such as fear of Peak Oil and geopolitical reasons for enhancing energy security (EWEA 2009b).

[4] The formation of specialized competences is a generic challenge in large-scale industrial transformations (Jacobsson 2002). For example, in the case of the emergence and growth of an electronics industry, there was a poor responsiveness of the Swedish higher educational sector to growing technological opportunities, at least compared to the US (Jacobsson et al. 2001). Indeed, in Sweden, the number of electronics engineers and computer scientists graduating per capita (at the BSc and MSc levels), was well below that of the US until the mid 1990s. For some years, the number of graduated engineers per capita in the US was over three times that in Sweden. Of course, Swedish industry suffered from lack of competences for many years.

[5] See also the interview with Filippo Gagliardi, project manager for the EWEA and TP Wind, in Wind Power Monthly, May 2010, page 52.

[6] In innovation system terminology, we focus on the function resource mobilisation (Bergek et al., 2008).

[7] A set of other professionals also need to gain insights into offshore wind energy. These include planners, environmental impact assessors, financiers and regulators.

[8] This figure is taken from GWEC and Greenpeace (2010) Advanced Scenario, see Appendix in this reference.
[9] In contrast, the projection made by IEA in 2009 would lead to a production of 2 300 TWh (GWEC and Greenpeace 2010).
[10] A global wind turbine industry of substantial magnitude would emerge where investments would rise from about 26 billion EUROs in 2007 to about 140 billion in 2020 and 202 billion in 2030 (GWEC and Greenpeace 2010).
[11] We have assumed an annual growth of 1 per cent. This is a conservative estimate, see EU (2011).
[12] This was 1 800 TWh in 2008.
[13] See ECF (2011) for technical and economic assessments of a set of decarbonisation pathways.
[14] The main components for the production of wind turbines are rotor blades, gearboxes, control systems, towers, electric generators, bearings, power converters, power transformers, castings and forging. For the offshore segment, foundations are added (BTM Consult ApS 2008).
[15] Britain was not included as there are, so far, no turbine manufacturers there. Research that goes further than this preliminary study should, however, also include Britain.
[16] The interviewees were given the opportunity to comment on the paper and eight did so.
[17] The detailed assumptions in that analysis are given in section 4.
[18] For Thanet, a 300 MW farm in progress, Vattenfall spends 40 000 man hours per week, uses 30-40 vessels on the site and up to 100 divers (Möller 2010a).
[19] All current megaturbine manufacturers are located in the Bremerhaven/Emden area in Germany. Other manufacturers are also developing larger turbines. For instance, Vestas is developing a 6 MW turbine (Ström Madsen 2010)
[20] These are so extensive that as late as the Copenhagen 2005 Offshore Wind Conference, the question was whether or not offshore wind would actually come to something and it was not until recently (the 2009 Stockholm Conference) that industry perceived that a diffusion will materialise (Giese 2010).
[21] In Germany, the TSO is responsible for grid connection to the transformer station but there are still uncertainties as to how the Law of 2006 regulating this matter should be interpreted (Wagner 2010).
[22] As the full capacity of a grid to an offshore farm is only used about 40 per cent of the time, the remaining capacity could be used to increase trading between countries (EWEA 2009a).
[23] Yet another institutional misalignment is inadequate measures to form markets for offshore wind power in some EU states. For instance, Sweden, with its long coastline, has tradable green certificates as the instrument to promote the supply of electricity from renewable energy sources. As this scheme is designed to make sure that investments are *not* made in currently higher cost alternatives, it gives inadequate incentives to investors (Bergek and Jacobsson 2010). Indeed, Vattenfall, the large state owned Swedish utility has three fully planned wind farms in Swedish waters that are on hold since the incentives are poor (Möller 2010a).
[24] These obstacles generate uncertainties for investors and may make it harder to finance projects (European Commission, 2008).
[25] Indeed, members of the industry argue that it is where the automobile industry was in the 1930s (Huhn 2010).
[26] It is, of course, also vital for the firms, one of which has decided to set up a special scientific department looking a number of years ahead in such areas as fluid dynamics, physics, wind measurement (including laser technology) and floating foundations (Arndt 2010).
[27] In contrast to offshore engineering in other sectors, turbines are not merely structural (static) artefacts, they are also mechanical (moving) which adds to the challenge of durability in these harsh environments.
[28] The offshore turbine designs are in a state of flux which means that there are many technical uncertainties, in particular in terms of the drive train. Moreover, vertical axis turbines have reappeared again as an option.
[29] The variations are made by a High Voltage Source Converter, HVDC-light (Carlson 2010).
[30] As part of the development of wind turbines, test facilities for blades, nacelles, drive trains and support structures are being built in many places in Europe, for example a wind tunnel in Oldenburg for tests of turbulence (Barth and Kärn 2010).
[31] Aeroelasticity, i.e. the science of rotor behaviour, is a knowledge field at Risö and Danish Technical University (Nörker Sörensen 2010).
[32] In general, large engineering efforts are needed to increase the efficiency of the turbines and one way forward is to see how new materials may be used (Quell 2010). Siemens, for instance, uses glass fibre together with steel in their direct drive generator (Cooke et al. 2010).

[33] The drag acting on a full running turbine is almost the same as if the rotor blades were replaced by a solid disc the size of two football fields. This creates a powerful force on the structure and the soil (Barth and Kärn 2010)

[34] These are erosion holes under offshore foundations.

[35] The problem is that in large wind farms, the first row of plants impact on the wind force for the second row etc. Currently, there are no models of such wakes after the first 2-3 rows which mean that the layout of the park is not optimised (Barth and Kärn 2010).

[36] This enables the control system to change the angle of the blades so as to catch the power of the wind in an optimal way.

[37] As these competences are applied to the challenges listed above, we would expect that some solutions are transferred to onshore wind turbines (Ross and Kölling 2010).

[38] For instance, in blade design, this integrated competence would find a balance between the structural engineer's desire to have thick blades with that of the aerodynamics' engineer who wants to have them as thin as possible. In addition, process engineering competence is required to make the production of blades more efficient (Månsson 2010).

[39] In order to better understand the whole wind power plant, including its support structure, an interdisciplinary approach for simulation is essential (Huhn 2010). This may imply integrating not only mechanical and electrical aspects, but also advanced software engineering skills. These engineers (ibid) *"...should be able to do simulation of the whole plant in one simulation tool and they should know controlling, e.g. the pitch for the rotor blades."*

[40] Trading on the EU electricity market could be handled by economists, but electrical engineers with an integrated economic competence would also be valuable (Carlson 2009).

[41] For reasons of confidentiality, we are unable to provide the detailed data.

[42] The number of engineers required at turbine manufacturers depends on the extent of vertical integration, but since almost the whole offshore market is covered, the ratio is assumed to represent an average for turbine manufacturers.

[43] In this feature, offshore turbines will require fewer engineers than onshore, since there is only one offshore region, the North Sea, including several countries (Quell 2010).

[44] These engineers are not only in R&D but also in production, procurement, marketing, project management and maintenance.

[45] Two alternative methods for calculations were used to estimate the magnitude of engineers needed by the turbine manufacturers. Together, these methods create a range from 3 500 to 12 400 engineers. The method presented above is chosen since it is based on fewer assumptions than the two alternative methods and is, therefore, considered to be more reliable. The first alternative method is based on the turnover per engineer (€/engineer). We use data from the related electrical and mechanical engineering industry in Sweden (excluding telecom) and ask the following question. If the wind turbine industry were to have the same turnover per engineer in 2020 as the Swedish industry had in 2008 (€3.6 million), how many additional engineers would be required? EWEA (2009b) estimates that the additional investments in wind turbines will be € 12.7 billion in 2020 (as compared to 2009). This would generate a need for 3 500 additional engineers by the turbine manufacturers. This figure is likely to be on the cautious side since much of Swedish R&D is registered in the service sector, undertaken either by independent firms or by subsidiaries of firms registered as electrical or mechanical engineering firms. The second alternative method takes its point of departure in the share of engineers in the total number of employees within the industry (engineers/number of employees). From our interviews, we know the number of engineers within the interviewed firms and from annual reports we find the total number of employees. From this we have calculated that 13.7 per cent of the employees in the turbine manufacturers are engineers. EWEA (2009c) estimates that 15.1 jobs/MW will be created in the wind turbine industry out of which 37 per cent will be in wind turbine manufacturers. An increase in the annually installed supply of 16 200 MW by 2020 creates a need for 12 400 (16200*15.1*0.37*0.137) engineers for the turbine manufacturers.

[46] For reasons of confidentiality, the detailed figures are not given.

[47] The method is different from that in section 5.1 due to two factors which both are related to difficulties in establishing an initial MW/engineer ratio. First, there are historically huge differences in the annual installed effect. Second, investment in offshore wind power is in the form of wind farms which normally take several years to construct. Calculating a ratio assumes, therefore, that we would have to estimate the construction

period for each farm, which is not possible. For both these reasons, the simpler method described above appears to be more reliable.

[48] These two examples illustrate the effects of an increased diffusion of wind turbines, including onshore.

[49] The engineering competences that will be most attractive to the producers of power grids are likely to be also sought after for the development of electrical vehicles (Normark 2009). In addition, many engineers (or a high proportion of the engineers) working in this sector will be retiring within the coming years (ibid).

[50] Additionally, the harsh environment offshore will increase the number of engineers needed for the operation and maintenance of turbines and their components (Karlsson 2009).

[51] These were identified through our participation in the EU sponsored Power Cluster project which included participants from Germany, Denmark, Netherlands, Sweden, Norway and the UK. Some of the academics interviewed took part in the project.

[52] The MSc programme Engineering Physics with a specialisation in Wind Physics being developed in Oldenburg may exemplify integration of these two fields (Kärn 2011).

[53] Aalborg uses an approach where as much as 50 per cent of the student's credits come from working with projects on industry based problems (Bak-Jensen 2010). This could possibly be an approach for integrating competences.

[54] As mentioned above, one is planned in Delft. In addition, The Bremerhaven (Fachhochschule) programme aims to provide an integrative competence and some of their students may become 'system integrators' (Seifert and Kühne 2010).

[55] In Germany, the ForWind institute and the WAB consortium are developing a part-time continuing studies programme for professionals in "Offshore Wind Energy" (Kärn 2011). This programme aims at delivering competences in a broad range of fields, e.g. physics, economics, project management and logistics.

[56] An additional issue is the scaling up of shorter courses that allow for specialists in, say, control engineering, to learn the specifics of the wind energy application. With the long lead times in setting up, and expanding, new MSc programmes, scaled up opportunities for re-training of engineers is a complementary response to a shortage of competences.

[57] The main benefit of science is that it generates competences so that society can create and respond to new opportunities; i.e. support for academic research is, as Salter and Martin (2001, p. 528) put it: "…an investment in a society's learning capabilities." This is why it is so important to integrate PhD education with research and this is why research should also be integrated with advanced undergraduate education. See also Pavitt (2001).

[58] For instance, Risö is now integrated into the Technical University in Copenhagen.

[59] There are some attempts to coordinate education within the field of wind power between universities in Europe. First, the Erasmus Mundus enables students in all fields of studies to study at another university within Europe (Nörker Sörensen 2010). More specifically for wind power, within the European Wind Energy Academy universities and institutes co-operate in research and education at a European level (van Bussel 2010).

[60] Industry has, of course, a responsibility to articulate their demand for new programmes and to induce potential students to pursue these.