blue mirror insights

Innovation and Technology Policy and the Development of a High-Skilled Workforce: Lessons from Renewable (Wind) Energy

Overview

The wind energy industry has largely developed over a 50-year period and has been highly innovative in devising reliable generating and storage systems both for on and offshore facilities. While the industry has been led by a series of international developers, manufacturers and operators, and educators, it is best viewed as a complex supply chain working together over extended periods: 5-7 years to realise a new generating facility; and, 15-30 years for the initial and extended operating life. Collective action across the supply chain, along with continuous high levels of support from national Governments (in the main) has created world leading clusters in a few countries (e.g. Denmark, Spain, Germany, USA and increasingly China and India). Due to the large number of companies involved across the supply chain, an important role of facilitating organisations and lead-industry bodies (national and international) has developed in ensuring awareness of emerging workforce requirements (numbers, skills and occupations). Despite the detailed mapping of workforce requirements, shortages still exist in some key occupations as the industry competes with other parts of the labour market and due to often remoteness of where wind energy is generated.

Background

Wind energy (onshore and offshore) is a well-established and rapidly growing industry starting with the first rural onshore single wind generators to the more recent offshore wind farms, the first of which was established in Vindeby in Denmark (1991). By 2008, global wind power capacity had reached 100 GW, and by 2014, around one million people were employed globally in the sector. In the next four years, the globally installed capacity had reached 560 GW and 200,000 jobs had been added to the sector's employment base[1]. The whole wind sector is highly dependent upon government support and decision making as regards feed-in tariffs, planning permission, licensing, and more broadly, as a key part of meeting their carbon reduction targets[2]. In order to develop and operate a single wind farm, either onshore or offshore, requires a whole supply chain of businesses and network of support organisations (usually amounting several hundred)[3]. The supply chain is changing due to the consolidation of suppliers and to changes to where the greatest margins are being made[4] (moving from manufacturing to services).

Growth Expectations and Forecast

Numerous studies have been undertaken covering expected global generating capacities levels down through regions, nations and sub-national regions, and these are usually firm forecasts for at least 5-7 years due to the development cycle of the industry.

Table 1: Global Wind Generating Capacities and Employment*

	Year		
	2015	**2030**	**2050**
Onshore – GW	405	2565	4401
Onshore – employment	1.1mn	3.5mn	3.8mn
Offshore – GW	514	2905	5476
Offshore – employment	1.1mn	2.2mn	2mn

*Includes direct and indirect employment

Source: IRENA (2017)[5]

It is often more useful to see these employment and generating levels in the context of renewable energy which in Europe in 2012-13 employed 1.2mn (303,445 in wind and much the same in biomass and solar) and was expected to grow to 2mn by 2020[6].

Employment and Workforce Predictions

The wind energy workforce is spread across the multiple stages of the process from planning a new facility through to its decommissioning. Work by the International Renewable Energy Agency has worked through each stage of an on-shore and an off-shore wind energy project and estimated the number of person days by occupation. The table below shows the level of human resources used at each stage across the whole process over a 5-7-year period and shows the relatively small proportion of ongoing employment once a facility has been commissioned.

Table 2: Human Resource Requirement and Deployment on Wind Energy Projects

Stage	Offshore – 500 MW Person Days	Onshore – 50 MW Person Days
Project planning	23,828 (1.2%)	2,580 (2.5%)
Procurement	7,299 (0.4%)	
Manufacturing	1,252,514 (63%)	18,967 (18%)
Installation and connecting	237,249 (12%)	34,480 (33%)
Operations and maintenance	25,073 (per year)	2,665 (per year)
Operations and maintenance (over 15-year operating lifetime)	376,095 (19%)	39,975 (38%)
Decommissioning*	97,453 (5%)	8,420 (8%)
Total	**1,994,438**	**104,422**

*Decommissioning could also give way to either replacement or repowering of facilities which can extend the life of the facility to 30-40 years rather than 15-20 years when initially installed. This would boost the levels of employment considerably and require a secondary installation (upgrade phase).

Source: IRENA (2017, 2018, 2019)[7]

Every nation with an interest in wind energy has undertaken their own studies to establish both workforce requirements to deliver their energy plans and its likely make-up[8]. Increasingly the interest has shifted away from onshore to offshore wind due to the scale of the operations possible and the achievement of increasingly lower generating costs[9].

National strategies and plans

Most countries have devised a national strategy to harness the potential of wind energy, and these are then reflected in energy plans (setting generating targets, tariff support), regional development actions (attracting inward investment, creating research and support resources), supply chain initiatives etc.[10] The strategies seek to engage potential contributors to the delivery of renewable energy targets and in creating extensive networks i.e. involving local government, project developers, facility financiers, generator operators, educators etc. An extensive facilitation process is set in train through the national plans and targets which seek to create alignment around an initial major project and to identify potential barriers to progress. The four primary pillars of these plans are usually: the wind energy supply chain, innovation, finance, and skills[11]. At the local level, the greatest focus is around sustainable direct employment generation which is often quite small[12].

Higher Education, Universities and Research Centres Networks

When national plans release and allocate investment to a local area for wind energy, there have been associated investments made in logistics facilities (port, storage area), research, testing and demonstration (e.g. Centres for Offshore Renewable Engineering in the UK[13], and the testing and demonstration centres in Denmark[14]), and in creating education and training networks (e.g. the Hull College Group). The real momentum behind the development of these facilities has been provided by the presence of a major manufacturing site of one of the leading turbine, mast and blade companies[15].

Objectives and Priorities for Workforce Development

While skills are seen as a critical part of delivering a successful national wind energy strategy and are embedded from the start[16], the core objective in workforce development terms is the raising of awareness of the large number of occupations involved, and that there are very few, very specialised ones. As no one party owns and operates the whole supply chain, and the resulting wind energy generating facility, every effort is made to keep all parties across the supply chain fully informed as to workforce needs of current, near term and future projects. Both skills shortages and skills gaps are identified through surveys[17]. This diffuse ownership of the skills agenda places an important role on the national industry bodies[18] (wind industry associations and other leadership bodies e.g. ORE Catapult) working with other national and regional partners to create an understanding and the commitment to develop specific skill sets. Depending upon the country, wind industry associations are supported by their national Government's specific wind energy support and promotion policies[19].

Workforce Development Process

Due to the development cycle of wind energy projects, there is a 5-7-year lead in before a wind farm starts generating electricity, means that with a proactive stance, specific skill requirements can be identified and met. In most developed countries there is a heavy reliance upon the existing national education and training infrastructure anticipating and responding to needs as they arise[20]. Key to anticipation is having wide agreement on the direction of investment, the speed of project development, the supporting context and continuity of government support, and the specific technology roadmaps around key elements of wind energy generation[21]. The wind energy organisations develop numerous annual status reports and share these widely: they are often sponsored by a major manufacturer or operator[22].

There is also a general view that: "The Offshore Wind Sector Deal anticipates that because of the strong apprenticeship systems in the British construction industry and heavy industry, relatively few training gaps will emerge as the industry grows."[23] The same is seen as being true also for Denmark and Germany, but not so for the USA. In the USA, where attracting and retaining key skills has been a major issue along with a weakness in the communication between educational institutions and employers[24].

Skills Requirements Definition

Several approaches have been adopted to define the skill sets specific to wind energy generation, and they include: skills, occupations and qualifications mapping[25], surveys and qualification harmonisation[26], analyses of skill shortages and skill gaps[27], reliability analysis[28], challenge mapping to competences[29], Delphi methods[30], career mapping[31], and science and innovation audits[32]. Common across all these studies are the following findings and observations[33]:

- Improve core STEM skills in industry generally and increase the number of candidates
- Introduce industry experience into current core training and education programmes subjects and projects related to wind energy
- Expand the cohort of graduate level wind energy generalists in engineering
- Harmonise vocational education and training programmes and qualifications – especially for technician roles
- Increase the emphasis on, and volume of operations and maintenance training ranging from modular through to full-time entry programmes
- Set-up joint academia-industry educational programmes using industry testing and demonstration equipment
- Introduce of big data analytics and robotics (autonomous systems) competences into wind energy suppliers and operators
- Early identification of emerging occupations identified relating to the manufacture of wind equipment (e.g. wind power design engineers), project development (e.g. wind resource assessment specialists), and production and operation (e.g. wind service mechatronics/ wind turbine technicians)

The emerging occupations have been recognised both in national standards (e.g. UK apprenticeship standard[34]), in standard occupational classifications (for wind energy technicians, wind tunnel technicians, wind turbine erectors, wind turbine mechanics, and wind turbine service technicians – two codes[35]), in occupational information databases like O*NET[36] and captured under the general 'renewable energy' category[37].

Overall workforce development process

There are several major components common across almost all national and pan-national wind energy workforce programmes, and these are:

- A widely developed, shared and agreed technology roadmap for all elements and stages of a wind energy project and facility[38]
- A cohesive network of stakeholders at the outset which brings together all aspects of the supply chain (project, manufacturing, human resource, etc.)
- Multiple and regular workforce assessment exercises identifying largely two things: the approximate level of overall employment currently and projections for the near future (around 10 years) which gives the scale of the resourcing required; and, the approximate numbers required by the stage of a project at the occupation level which focuses attention on the critical, few occupations which need addition effort in resourcing
- Regular surveys and analysis to identify specific skill shortages and skill gaps covering all stages, all parts of the supply chain, and occupation specific studies – close being an annual exercise
- Recognition of occupations in national and pan-national standards and in standard occupational classifications systems – usually happens after a considerable period – which helps both education and training providers and careers advisory services
- Building on regional clusters of wind energy businesses to help them develop and acquire new specialist skills over a relatively well-defined periods of time – the growth of the

industry is governed by the rate of expanding capacity (set by national targets and commitments) and provides significant lead times for recruitment, education and training
- Supporting successful regional clusters which are centred on major manufacturers (turbines, blades, etc.) working with major project developers through an active long-term government energy development and support programme
- Leveraging of existing economic activities in support of wind industry development which includes the transfer of employees from related sectors[39]
- Governments allowing and recognising corporate 'wind competences' development by major wind energy businesses through acquisitions and mergers with competitors and so build critical mass, and corporations working closely upon the manufacture, supply, installation and servicing of equipment acquiring knowledge of facilities in use and making improvements in design and manufacture as a result (incremental innovation)
- Identification of the cross-sector technology and skills opportunities between wind energy and other sectors[40] through fostering technical and research networks
- Governments supporting specific workforce development initiatives through the investment in research and demonstration facilities (often linked to universities) and testing and development centres located within or close to key manufacturing companies and other parts of the supply chain
- Active networks bringing together all aspects of the supply chain to develop a shared agenda and these often highlight the areas for state and collective investment[41]

End Notes

1: Figure 6: Overview of key milestones achieved by the wind industry since 1982, page 23 in IRENA (2019) Future of Wind: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects. (A Global Energy Transformation Paper). International Renewable Energy Agency, Abu Dhabi. 88 pages

2: Jones, G. and Bouamane, L. (2011) Historical Trajectories and Corporate Competences in Wind Energy. Working Paper 11-112 Harvard Business School. Looks at the period of 1970-2010 and shows the crucial role of public policy shaping what was originally a rural serving industry and how the industry developed across the USA, Denmark, Spain, Germany, India and China. Just taking California as one example there were 15856 wind turbines installed on land in 1992 of which nearly 50% were produced in the USA with the bulk of the remainder made in Denmark. See: Figures ES1, Wind roadmap to 2050: tracking progress of key wind energy indicators to achieve the global energy transformation (pages 12-13)

3: The UK wind energy supply chain is made-up of around 400 companies (HM Government, 2019, Industrial Strategy. Offshore Wind Sector Deal. Page 32); in the USA there are 133 prime members (Ayee, G. et al, 2008, "Wind power: generating electricity and employment", Chapter 11 in Manufacturing Climate Solutions Carbon-Reducing Technologies and US Jobs. Centre on Globalization, Governance and Competitiveness, Duke University, Figure 11: US Wind Power Value Chain with Industry Participants, page 36); in the German supply chain there are 240-250 companies (German Wind Energy Association (BWE) (2018), Economic Report: An Overview of the German Wind Industry. 228 pages); and in the Danish wind energy supply chain there are 200 main businesses (Danish Wind Industry Association, website).

4: Nielson, V.V. (2017) The Danish Wind Cluster. The Microeconomics of Competitiveness. Working Paper, Harvard Business School. Margins are higher in servicing (17%) rather than in, say, manufacturing a turbine (7%). Consolidation has been a major part of the industries development with both opportunistic and planned takeovers shaping developments in Denmark, Germany and the USA. A family tree emerges over the 1970-2010 period during which dominant wind turbine design models became established for both on and offshore wind farms. The process of consolidation also marked a process of competence development at the corporate level which allowed Siemens and Vestas to acquire new capabilities and facilities to support their growth in wind energy. See: Jones and Bouanne (2011) op. cit.

5: IRENA (2017) Renewable Energy Benefits: Leveraging Local Capacity for Onshore Wind. International Renewable Energy Agency, Abu Dhabi. The employment levels projected over time vary and by 2019, IRENA had reduced the near-term levels and increased for 2050 levels. In part these changes were due to changes in the phasing of projects and labour intensity in several countries involved in harnessing wind energy. It is important to put the employment numbers for wind energy in context and alongside those for solar photovoltaic at 6.3mn and 12 mn for biofuels (ILO and EU, 2011, Skills and

Occupational Needs in Renewable Energy, page 7). At the regional level, see Collier, R. et al (2019) California Offshore Wind: Workforce Impacts and Grid Integration. Centre for Labor Research and Education, University of Berkeley. 95 pages. University of Buffalo (2019) Clean Energy Workforce Assessment for Western New York. Report prepared for UB TCIE and Alfred State College of Technology by the UB Regional Institute. Green Alliance (2014) UK Offshore Wind in the 2020s. Creating the conditions for cost effective decarbonisation. Report supported by Dong Energy, Statkraft, and Vattenfall. Green Alliance, London. 32 pages.

6: EU Skills Panorama (2014) Analytical Highlight. Focus on Renewable Energy Sector. This piece of work also examines both employment changes under an energy efficiency and decarbonisation scenarios. KPMG (2019) The Socio-economic impacts of wind energy in the context of the energy transition. Report for Siemens Gamesa. 126 pages. Full decarbonisation by 2050 increases the level of employment in wind industry from 1.53mn (current trajectory) to 2.97mn (decarbonisation pathway) Chart: Decarbonising energy will create millions of renewable energy jobs, page 86. International Economic Development Council (2013) Creating the Clean Energy Economy. Analysis of the Offshore Wind Energy Industry. IEDC, Washington, DC. 96 pages. Table 1: Economic Development and Job Creation Projections in Europe and the United States, page 8.

7: IRENA (2017) Renewable Energy Benefits: Leveraging Local Capacity for Onshore Wind. (Tables 2.2 - planning; 2.5 - manufacturing; 2.8 – installation and connection; 2.10 – operations and maintenance and 2.11 - decommissioning); and, IRENA (2018) Renewable Energy Benefits: Leveraging Local Capacity for Offshore Wind. (Tables 3.1 – planning; 3.2 – procurement; 3.3 – manufacturing; 3.4 installation and connection; 3.6 operations and maintenance; and 3.7 – decommissioning). International Renewable Energy Agency, Abu Dhabi. The replacement and repowering of facilities is especially important as by 2020, 28% of the installed wind turbine capacity in Europe had crossed the 15-year lifetime, and this marketplace in Europe is expected to grow significantly over the next 10 years. When repowering takes place, the installed capacity is usually greatly increased e.g. the UK Delabole wind farm (initially commissioned in 1991) was repowered between 2009 and 2011 and led to a two-fold increase in the plant's installed capacity. The core of this repowering comes from replacing 1MW turbines with new models of up to 4MW capacity (IRENA, 2019, page 29). More recent developments driven by Denmark show the future build programme continues to grow (e.g. "Denmark boosts green plan with energy islands", Financial Times May 21st, 2020; and, "Orsted/ Offshore wind: a verdant outlook", Financial Times, May 26th, 2020)

8: In looking at employment numbers for a country related to wind energy, it is particularly important to take note of the level of subsidy provided by the national Government. For example, in Denmark, it is estimated that there is a subsidy of $9-14,000 per worker employed in the industry. H. Meyer (2009) Wind Energy – The Case of Denmark. Centre for Politiske Studier (CEPOS), Copenhagen. Pages 34-35. The Massachusetts Clean Energy Center modelled growth from 2017-18 to 2029-30 at the occupation level (2018 Massachusetts Offshore Wind Workforce Assessment) and identified nearly 3000 total job years equivalent of work (Table 3, Biennial New Job-Years by Occupation, 2017-2030). The directness of the link between power generating capacity and employment generation is not a hard one and ratios vary greatly based on technology, labour intensity, design features (e.g. plug-in replacement technology, gearbox integration with the turbine, etc.), location, etc. See: Aldieri, L. et al (2020) "Wind power and job creation", Sustainability, 12, 45, which covered 27 reports and papers over the 2001-2019 period and concluded that each project required its own unique assessment and few jobs were generated post-project completion. Megavind (2013) The Danish Wind Power Hub. Strategy for Research, Development and Demonstration. Danish Wind Industry Association, Frederiksberg. 52 pages. This report noted that even by 2013 the Danish component and service suppliers had invested heavily in automation despite small production runs, the clustering together and sharing of production facilities, flexible production facilities that can be moved to where the markets are active, and the modularisation and standardisation of components (page 15). The diversity of operating conditions is however still meaning there is a high level of unique components manufactured and often this is a major source of competitive advantage.

The make-up of the workforce has also prompted calls to assist in the re-training and redeployment of personnel from the oil and gas sector to the renewable one, and in particular, offshore wind (IRENA, 2019)

9: Global Wind Energy Council (2018) Global Wind Report 2019. GWEC, Brussels. 61 pages; Deutsche Wind Guard (2019) Status of Onshore Wind Energy Development in Germany 2019; German Wind Energy Association (BWE) (2018) Driven by the Wind. Arguments for Wind Energy and (2018) Wind Industry in Germany Economic Report: An Overview of the German Wind Industry. 56 and 228 pages respectively. Kalimikov, A. and Dykes, K. (no date) Wind Power Fundamentals. MIT Wind Energy Group and Renewables Energy Projects in Action. By 2050 is projected that onshore and offshore wind generation could be as low as 0.03 US$ per KWh (IRENA, 2019, page 13).

10: National Renewable Energy (2018) 2018 Offshore Wind Technologies Market Report. US Department of Energy, Office of Energy Efficiency and Renewable Energy. 94 pages; Department for Business, Energy and Industrial Strategy (2020)

 The views and opinions expressed in this note are those of BMI and do not necessarily state or reflect those of the Gatsby Charitable Foundation who funded the work.

Offshore Wind Sector Deal. HM Government, London; HM Government (2013) Offshore Wind Industrial Strategy. Business and Government Action. Just taking cost reduction as one example for the UK offshore wind energy you find multiple parties working together across the whole lifecycle e.g. The Crown Estate, ORE Catapult, Offshore Wind Accelerator, Renewables UK, etc. See: Offshore Wind Cost Reduction Initiatives in DNV GL Energy (2014) Offshore Wind. A Manifesto for Cost Reduction. 24 pages

11: HM Government (2014) Overview of Support for the Offshore Wind Industry. 31 pages. Context is especially important here as the size of the sea basin to be accessed and developed, which for the UK is 192,400 km^2 which is 44% of the Central and Southern North Sea basin, and is virtually the same size as Belgium, Denmark, Germany, Netherlands and Norway put together. Source: Table 1, page 6 in Energy Research Centre of the Netherlands (2011) Roadmap to the Deployment of Offshore Wind Energy in the Central and Southern North Sea (2020-2030).

12: Noonan, M. (2019) UK Offshore Wind: Realising the Sector Deal Opportunities. ORE Catapult notes there being 7200 employed in offshore wind; Hattam, C. et al (2015) Understanding the Impacts of Offshore Wind Farmers on Well-being. The Crown Estate. This report shows 3151 were employed in offshore wind in 2010, 6830 in 2013, and around 7000 indirectly in the supply chain. Also see: Renewables UK (2011) Working for a Green Britain. Volume 2: Future Employment and Skills in the UK Wind and Marine Energy Industries. Renewables UK, London. 40 pages

13: HM Government (2011) Centre for Offshore Renewable Engineering which describes the policy and the initial five centres in Tyneside, Teesside, The Humber, Great Yarmouth and Lowerstoft, and Sheerness. The Sheerness centre is further described in detail in Locate in Kent (2016) The South East CORE Centre for Offshore Renewable Engineering. 30 pages. We see the same developments in the USA in Texas (Texas Tech University which focuses on three area: energy systems, wind engineering, and measurement and simulation) and Maine (Wind Energy Sector: Employment Opportunities and Requirements. 2010. Maine International Consulting for the Maine Composite Alliance and Maine Wind Industry Initiative); Denmark and Germany.

14: Neilson, V.V. (2017) op. cit.; Danish Wind Industry Association (2012) Denmark – the Wind Power Hub: Transforming the Supply Chain. Danish Wind Industry Association. 80 pages. This report raises the potential for a shift in the location of suppliers to closer to where the demand is and having the ability to meet new and modified demands. MEGAVIND (2016) Test and demonstration facilities for wind energy needed to promote a competitive wind industry in Denmark. Danish Wind Industry Association, Frederiksberg. 40 pages. Overall in Denmark there are 12 national test sites, 4 universities and 7 training institutions which focus on wind energy (World Wind Energy Association, 2018)

15: Neilson, V.V. (2017) op. cit. where he defines the cluster as being made-up of: turbine manufacturers, project developers, research and test institution, government institutions, collaborative facilitators (overseeing partners creating a common agenda), and suppliers and related industries; Collier et al (2019) Chapter 2: Lessons from Abroad: Denmark pages 19-20; Meyer (2009) op. cit.

16: Denmark has centralised decision-making over most aspects of national wind planning through the Danish Energy Agency and operated a national master plan since 1997 for offshore wind growth. The plan allows the Agency to guide permits through local planning agencies, iron out stumbling blocks with environmental reviews, coordinate payment deals with commercial fishing groups to compensate for loss of fisheries and ensure grid connections and immediate offtake contracts with local utilities. See: Collier, R. et al (2019) op. cit., page 20.

17: Surveys have been undertaken at regional, national and multi-national levels e.g. SET Plan (2018) Offshore Wind Implementation Plan. 70 pages; TP Wind (2013) Workers Wanted: The EU Wind Energy Skills Gap. European Wind Energy Technology Platform; McGovern, G. (2009) One Industry – one qualification standard. WINDSKILL Intelligent Energy Europe, European Wind Energy Skills Network. Paper presented at the EU Sustainable Energy Week.

18: Nielson, V.V. (2017) op. cit.

19: Government support works across multiple areas: tariff subsidies, tax incentives, R&D funding and facilities directly to companies and universities, start-up and entrepreneurship programmes, free-port status, etc.

20: ILO and EU (2011) Skills and Occupational Needs in Renewable Energy. 202 pages; for specific develop roadmaps see: Figure 12: Developer Journey Map for the Deployment of Onshore Wind Projects, page33 ; and Figure 16: Developer Journey Map for the Deployment of Offshore Wind Projects, page 47 in Department of Energy and Climate Change (2011) UK Renewable Energy Road Map. DECC, London. This roadmap has been updated in 2012, 2013, and then 2015 and every two years after that.

21: SNC Lavalin/Atkins and K&L Gates (2019) US Offshore Wind Handbook. Version 2. 86 pages; Energy Research Centre of the Netherlands (2011) Roadmap to the deployment of Offshore Wind Energy in the Central and Southern North Sea (2020-2030).

22: DECC (2011) op. cit.; IRENA (2019) op. cit.

23: Collier, R. et al (2019) op. cit., page 15; the same can be said for Germany too where BIBB and BBNE are active on projects to address skills shortages (World Wind Energy Association with the Korea Wind Energy Industry Association, 2018, Germany, WWEA Policy Paper, Series PP-02-18-B, page 49).

24: Keyser, D. and Tegen, S. (2019) The Wind Energy Workforce in the United States: Training, Hiring and Future Needs. National Renewable Energy Laboratory, Golden, Colorado. Page 37; Baring-Gould, I. et al (2010) Wind Energy Workforce Development: A Roadmap to a Sustainable Wind Industry. National Renewable Energy Laboratory, Golden, Colorado.

25: SQW Energy (2008) Skills and Employment in Wind, Wave and Tidal Sector. Report to the British Wind Association.

26: McGovern, G. (2009) One industry – one qualification standard. Paper presented at the EU Sustainable Energy Week. This is a part of the Windskill Initiative. A Systematic Approach to Wind Energy Qualifications. Project Number EIE/06/051-S12.444469.

27: Bain and Company (2008) A Closer Look at Wind, Wave and Tidal Energy in the UK. Report for the British Wind Energy Association; Renewables UK (2013) Working for a Green Britain and Northern Ireland 2013-2023. Employment in the UK Wind and Marine Energy Industries. Renewable UK, London. 56 pages. See: Figure 7.1: Impact of hard-to-vacancies on organisational performance, and Table 7.1: Incidence of hard-to-fill vacancies – both page 43. One factor highlighted in this analysis was the industry was characterised by many small firms less able to develop their own internal development paths.

28: ISET (2006) Reliability of Wind Turbines – Experiences of 15 years with 1500 Wind Turbines. ISET, Germany. Makes use of 200,000 turbine operating hours of data to look at where failures in a wind turbine occur which both drives engineering improvement and course content for the development of wind turbine engineers and technicians. See also: Echavarria, E. et al (2008) "Reliability of wind turbine technology through time", Journal of Solar Energy Engineering, Vol 130. 8 pages

29: Jacobsson, S. and Karltorp, K. (2011) Formation of competences to realise the potential of offshore wind power in the European Union. Working Paper, Environmental Systems Analysis, Chalmers University of Technology, Gothenburg. 39 pages. In Figure 4 the authors map the specific challenges faced in offshore wind engineering with equally specific engineering competences (these are split between deep and integrated competences). The point is also well made that the modification of existing engineering programmes is sufficient to meet most foreseen skill requirements in the wind energy sector.

30: Coppedge, R.H. (2015) An Assessment of Knowledge and Skills Competencies for Wind Energy Technician I: A Delphi Methodology. Ph.D. Thesis. Texas A&M University. 155 pages. The study focuses on curriculum on offer for wind energy technicians and the skills and knowledge required on-the-job by undertaking successive surveys of current job holders.

31: Hamilton, J. and Liming, D. (2010) Careers in Wind Energy. US Bureau of Labor Statistics. 18 pages. Reviews all occupation and most notably that of the wind technician.

32: University of Newcastle upon Tyne (2017) Offshore Renewable Energy Science and Innovation Audit. UK Department for Business, Energy and Industrial Strategy, London. 114 pages. This work combined both an analysis of education and training providers focusing on offshore wind and also highlighted some of the major skill shortages.

33: Taken from: TP Wind (2013) op. cit.; EITP (2020) EITP Wind Roadmap. European Technology and Innovation Platform on Wind Energy (pages 22-23)

34: Wind Turbine Technician is an option within STO 154 Maintenance and Operations Engineering Technicians (Level 3) and listed on the Institute of Apprenticeship and Technical Education website.

35: American Wind Energy Association website under "Standard Occupational Classification Codes for wind energy professionals". The Bureau of Labor Statistics have also assigned a NAICS code of 221115 for wind electric power generation (started in 2012) which will need to collect four-year's worth of data prior to release of any information covering workforce information, including injury and illness rates, wage determination, etc.

36: O*NET includes four occupations: wind energy operations manager (11-9199.09), wind energy project manager (11-9199.10), wind energy engineer (17-2199.10), and wind turbine service technicians (49-9081.00).

37. For example, ESCO, has the following two occupations: renewable energy engineer (ISCO 2149.7.3) which covers offshore wind project engineer; and, wind turbine technician (ISCO 7412.12).

These three notes capture two processes: one is the expansion in the volume of work on wind energy across a few key roles, and, the need to compress a set of skills in order to minimise the labour requirements to work on difficult to access, and potential hazardous sites. Similar processes can be seen on offshore oil and gas rigs where the need is to minimise costs, and to optimise skills mix in order to maintain currency (minimise skills atrophy). The work of the ILO and EU found similar "wind occupations": wind resource assessment specialist (in project development), windsmith (covers millwright, mechanical technician or fitter/wind service mechatronics technician), and wind service mechatronics (Table 4.2: Occupations in wind in Skills and Occupational Needs in Renewable Energy, 2011, pages 69-70).

38: International Energy Agency (2013) Technology Road Map Wind Energy. IEA, Paris. 63 pages (see Figure 3: Capacity factors of selected turbine types, page 12; Figure 15: Target for cost reductions of land-use wind power in the United States, page 28); IRENA (2016) Innovation Outlook for Offshore Wind Technology. International Renewable Energy Agency, Abu Dhabi; IRENA (2019) Future of Wind: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects (A Global Energy Transformation Paper). International Renewable Energy Agency, Abu Dhabi. 88 pages. See: Figure 28: Anticipated timing and importance of innovations in offshore wind technology, page 55. This figure identifies the agreed path and timing of key developments (14 major items) and splits them across six areas of the usual project lifecycle: development, turbine manufacture, support structures, electrical interconnection, installation, and operations, maintenance and services. One of the key elements in the roadmap work for wind energy are the projections for generating capacity (see IRENA, 2019, Figure 4: Comparison of scenarios for the global energy transition with a focus on wind power generation, page 20, which takes the output of nine studies which broadly agree on the scale and share of wind energy going forward to 2040-2050) and the rate of cost reduction required to achieve a sustainable market share and meet carbon reduction targets (IRENA, 2019, page 13, which shows that both onshore and offshore wind are on track to meet 2030 and 2050 targets).

One of the most significant developments in wind energy has been the growth of hybrid renewable energy facilities where wind is combined with hydro, solar, hydrogen, and battery storage. For example, in 2018, the world's first hybrid offshore project (Batwind) connected the largest floating offshore wind farm (Hywind) with a 1.2 MW battery storage system (Equinor, 2018, World's first floating wind farm has started production. Stavanger, Norway; also: Zion Market Research, 2019, Global solar wind hybrid systems market: by type, industry size, share, applications, trends, analysis and forecast, 2018-2025. Zion Market Research). These hybrid projects are found in all of the major wind energy markets.

39: IRENA (2019) op. cit.; Skills Development Scotland (2019) Oil and Gas Transition Training Final Review. Report by Hall Aitken for Skills Development Scotland. Summary Report. 9 pages. Reviews the 3529 training grants of up to £4000 per person with a success rate of 87 per cent.

40: Offshore Wind Industry Council (2019) The UK Offshore Wind Industry: Supply Chain Review. 108 pages. The offshore wind industry is a relatively young sector with much of the core technology evolving from solutions used in the onshore wind market. There has been a significant input from the oil and gas sector particularly in relation to installation and offshore operation. Conventional power generation engineering has supported turbine design and the aerospace sector has provided experience of composites and manufacturing, and remote sensing (e.g. Hasager, C.B. et al, 2008, "Remote sensing observation used in offshore wind energy", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 1 (1), 67-79). (see Section 2.3 Cross-Sector Synergies, and Table 1: Cross-sector technology transfer opportunities)

41: A good example of a joint innovation programme is captured in The UK Offshore Wind Industry: Supply Chain Review (2019) op. cit. which concluded the following areas could be the priorities of an Offshore Wind Innovation Hub:

- Reduce the cost of offshore electricity generation
- Enhance the efficiency of offshore turbine systems
- Extend the working life of systems or components
- Reduce the cost of operation and maintenance
- Increase the efficiency of electrical distribution
- Achieve UK employment and/or IP to support export opportunity
- Reduce the potential intermittency of systems
- Demonstrate a circular economy e.g. recycling, repurposing, refurbishing
- Enhance health and safety