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Occupational safety and health in the wind energy sector

European Risk Observatory
Report

European Agency for Safety and Health at Work

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Table of contents

List of tables and figures

Abbreviations

Cw	continuous wave
CWIF	Caithness Windfarm Information Forum
dB	decibel
dBA	decibel adjusted
EMF	electromagnetic field
ESTA	European Association of Abnormal Load Transport
EU	European Union
EU-OSHA	European Agency for Safety and Health at Work
EWEA	European Wind Energy Association
FEM	European Federation of Materials Handling
GRP	glass-reinforced plastic
GW	gigawatt
GWO	Global Wind Organisation
HAZID	Hazard in design
IWEA	Irish Wind Energy Association
m/s	metres per second
MW	megawatt
NIOSH	National Institute for Occupational Safety and Health
NREAP	national renewable energy action plan
OSH	occupational safety and health
PDCA	plan–do–check–act
PPE	personal protective equipment
VARTM	vacuum-assisted resin transfer moulding
WBV	whole body vibration

1 Introduction

Wind energy is renewable and clean, and produces no greenhouse gas emissions. In 2012, it accounted for 11.4 % of the European Union's (EU's) power capacity and 26.5 % of all new power capacity in Europe (EWEA 2012a). As the EU power sector continues its move away from oil, coal and nuclear fuels, wind energy has experienced tremendous growth over the past decades, and this is expected to continue. Annual installations of wind power have increased steadily over the past 12 years, from 3.2 gigawatts (GW) in 2000 to 11.9 GW in 2012, a compound annual growth rate of 11.6 %. In 2010, there were 70,488 onshore wind turbines and 1,132 offshore turbines across the EU (European Wind Energy Association, 2013). A total of 106 GW is now installed in the EU, an increase in installed cumulative capacity of 12.6 % compared with the previous year. The wind power capacity installed by the end of 2012 would, in a normal wind year, produce 231 terawatt-hours of electricity — enough to cover 7 % of the EU's electricity consumption. The total number of wind turbines worldwide at the end of 2012 was around 225,000, spread over 79 different countries (Global Wind Energy Council, 2013).

In its recently published research agenda (EWEA, 2010), the European Wind Energy Technology Platform (TP Wind) proposes an ambitious vision for Europe. In this vision, 300 GW of wind energy capacity will be implemented by 2030, representing 25 % of the EU's electricity consumption. Moreover, the TP Wind vision includes a sub objective on offshore wind energy, which it believes should represent 10 % of EU electricity consumption by 2030. Wind energy is a mainstream renewable power source and, if the right steps are taken, this source will be essential in meeting Europe's 2020 renewables target, tackling climate change, strengthening energy security and creating new jobs (Europa, 2009).

At present, the European wind energy sector provides jobs for 192,000 people, and many more well-trained workers are needed in areas ranging from manufacturing to project management. It has been predicted that by 2020 there will be 446,000 jobs in the wind energy sector in Europe (EWEA, 2012b).

Growth in the wind energy sector can be attributed to a number of factors, including financial confidence, technological advancements, legislative support from local governments and increased public support and awareness. As the EU's wind energy industry continues to grow, new challenges begin to emerge. With an increasing number of workers now employed in various aspects of the wind energy sector, occupational safety and health (OSH) becomes a prime concern. Many aspects of siting, erecting, maintaining, servicing and possibly dismantling wind turbines are unique, and even if most of the job hazards that these workers will face are not, the working environments and combinations in which they are found create unique challenges. New technologies or working processes associated with wind energy will also lead to new hazards, which call for new combinations of skills to deal with them (EU-OSHA, 2013). Wind energy is a relatively 'new' industry, and some of the workers may not be fully aware of the hazards that exist in this work environment. In addition, the speed at which the EU wind industry is expanding could lead to skills gaps, with inexperienced workers involved in processes for which they have not been trained, and who therefore put their safety and health at risk.

Although wind energy is considered 'green' and good for the environment, it does not necessarily mean it will be good for the health and safety of workers. Wind energy workers can be exposed to hazards that can result in fatalities and serious injuries during the various phases of a wind farm project. The objective of this report is to provide an in-depth and comprehensive overview and analysis of the OSH challenges in the wind energy sector in order to raise awareness and thereby support good OSH, so that the jobs in this sector are jobs that provide safe and healthy working conditions.

This review considers the OSH issues in the wind energy sector, both onshore and offshore, within the EU Member States. The activities associated with wind energy — from the design and manufacturing of wind turbine parts, through the transport, installation and maintenance, to emergency rescue and waste treatment — are explored. OSH issues associated with working in remote areas, extreme weather conditions, confined spaces, awkward postures, electrical risks, falls from height, musculoskeletal disorders, physical and psychosocial loads, various aspects of work organisation and exposure to dangerous substances (e.g. at the production stage but also during maintenance operations) are included.

Other aspects, such as subcontracted work, worker training and characteristics of the workforce (e.g. gender, age), are also addressed where relevant. Further, the possible conflicts between OSH and environmental requirements are explored.

1.1 EU policy regarding wind energy

The EU is committed to reducing its greenhouse gas emissions by at least by 20 % by 2020. The production of energy accounts for 80 % of all greenhouse gas emissions in the EU. To reach the 20 % reduction target, the EU has recommended the following measures on energy: to improve energy efficiency by 20 % by 2020; to increase the share of renewable energy to 20 % by 2020; and to develop an environmentally safe carbon geological storage policy in the EU (Europa, 2009).

The Renewable Energy Directive (2009/28/EC) addresses various subjects related to renewable energy in Europe. The directive required that each of the 27 EU Member States develop a national renewable energy action plan (NREAP) by 30 June 2010. Each Member State outlined in its NREAP how it intended to meet the 2020 target. The European Environment Agency produced a report summarising information from the NREAPs, which highlighted that the most important contribution would be the energy generated from wind power, which was predicted to reach 40.6 % (onshore wind power contributes 28.2 %) of all renewable electricity.

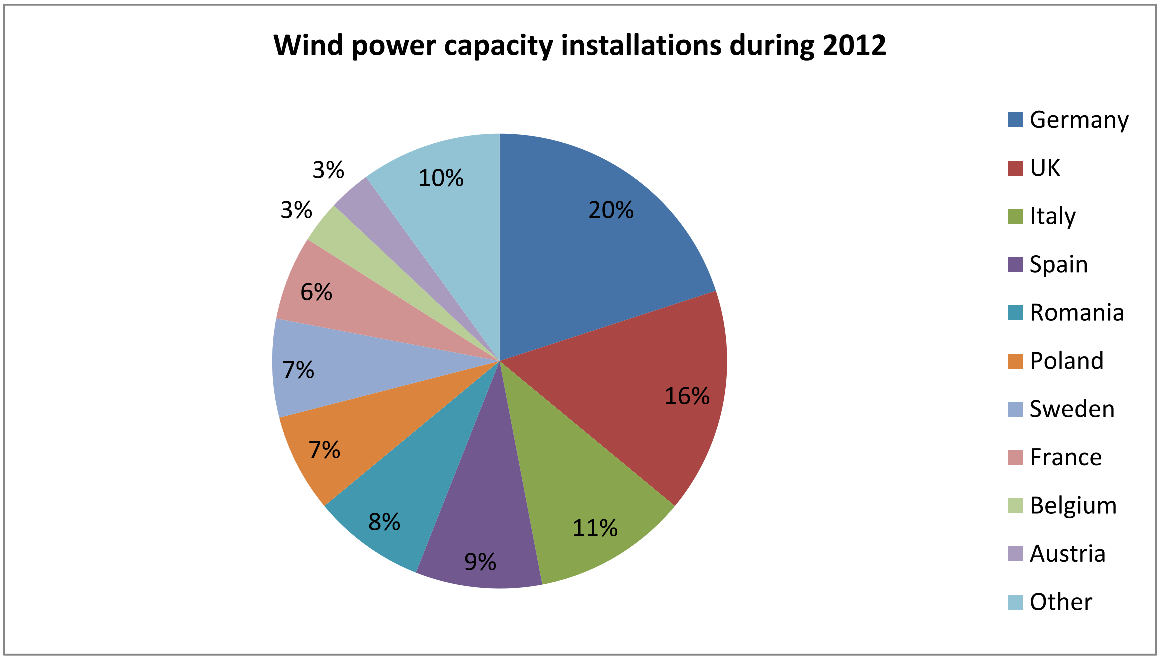
The European Commission supported offshore wind energy in its 2009 energy work programme, because the use of maritime wind energy can make a significant contribution to the goals of the New Energy Policy. These goals are (i) reducing greenhouse gas emissions, (ii) enhancing the security of the supply and (iii) improving the competitiveness of the EU. The utilisation of offshore wind energy may be 30–40 times greater in 2020 than the capacity supplied by offshore wind energy today. If the offshore wind energy production grows as planned, it will have a major impact on the working environment. The main challenge will be to find trained and experienced workforces, as future offshore wind energy developments will have to compete with both the onshore wind energy sector and the oil and gas industry for financing, equipment and expertise (Europa, 2009).

1.2 The present situation and future of wind energy in Europe

At the moment, Europe is the leading global supplier of wind turbines. It also has the largest working wind energy capacity. In fact, two-thirds of the current global working wind capacity is located in the EU, and five of the top ten wind turbine manufacturers are located in Europe (European Commission, 2011a, 2012). Europe's installed wind power capacity reached 100 GW in 2012; enough to power over 57 million households each year and meet around 7 % of the EU's electricity demand or the total electricity consumption of the inhabitants of Sweden, Ireland, Slovenia and Slovakia combined.

In 2010, Spain and Germany were the main wind energy generators in Europe, followed by the United Kingdom, France, Portugal, Italy and Denmark (Eurostat, 2012). With regard to installing new wind turbines, in 2012, Germany, United Kingdom, Italy and Spain were leading in Europe (Bundesverband WindEnergie, 2011). Among the emerging markets of Central and Eastern Europe, Romania and Poland had record years — both countries installed around 7 % of the EU's total annual capacity.

Figure 1: shows individual EU Member States' market shares for new capacity installed during 2012



Source: EWEA

By the end of 2011, Germany and Spain had installed more than 20,000 wind turbines, which were mainly located on inland or coastal areas. The wind energy market in Spain experienced modest growth in 2011, even though it had experienced setbacks as a result of the economic crisis, which has lowered the forecast output for offshore wind energy for 2020 by 75 % [from 3,000 MW (megawatts) to 750 MW], but the target for onshore wind has been maintained at 35,000 MW. Germany is progressing strongly with the development of offshore wind energy. At present, about 200 MW of offshore wind farms are in operation in Germany. Offshore wind farms, which will generate 25,000 MW of power in the North Sea and Baltic Sea, are planned to be built by 2030. If Germany reaches this target it will need to install about 5,000 new wind turbines (Global Wind Energy Council, 2012; Nicola, 2012).

The United Kingdom and Denmark are currently the leaders in developing and installing offshore wind energy. Denmark established its first offshore wind farm in 1991, and, in 2010, the installed wind capacity was 3,545 MW, of which offshore wind power accounted for 505 MW (Danish Energy Agency, 2012). At the moment, there are 12 offshore wind farms; two offshore wind farms are under construction and three wind farms are in future plans in Denmark (Global Wind Energy Council, 2012). The United Kingdom has one of the best wind resources in Europe. By the end of 2011, offshore wind power accounted for over 2,000 MW in the United Kingdom, enabling it to maintain its status as a world leader in offshore wind energy generation. At the same time, the total wind energy market size was 6.5 GW in the United Kingdom. In the United Kingdom, the plan is that offshore wind energy could contribute up to 18 GW, and onshore wind up to 10–13 GW, of installed capacity by 2020 (Global Wind Energy Council, 2012). One obstacle in wind energy development in the United Kingdom is that there is an increasing and well-organised opposition to wind energy, leading to political and media debate. This debate has affected what is happening at the local level, with only 26 % of onshore wind projects receiving approval (Global Wind Energy Council, 2012).

With regard to wind turbine manufacturing, Denmark and China are strong players. The Danish company Vestas is the leader according to market share, and there are three other Danish manufacturers among the top 10 (European Commission, 2011a). Four Chinese wind turbine manufacturers are found in the top 10. However, at present, wind turbines manufactured in China have been sold only in China (European Commission, 2011a).

The other main countries that are rapidly increasing their wind energy capacity are China, the USA and India. These, together with Latin America, are the main areas where new installations of wind power will grow most in the future (Bundesverband WindEnergie, 2012). In 2011, the installed wind power of these countries was as follows: China (62.7 GW), USA (46.9 GW), Germany (29.1 GW), Spain (21.7 GW) and India (16.1 GW) (Bundesverband WindEnergie, 2011).

In conclusion, Europe's wind energy potential is fairly extensive (European Environment Agency, 2009). Onshore wind energy has been concentrated on the agricultural and industrial areas located in north-western Europe. The largest offshore wind energy potentials are found in low-lying areas in the North Sea, the Baltic Sea and the Atlantic Ocean, although there are local opportunities in areas of the Mediterranean and the Black Sea. The wind energy potential of the deep offshore regions is even higher than of low-lying offshore regions; however, the costs are also higher, and this will impede the development of deep offshore wind energy in the imminent future. The environmental constraints appeared to have some impact in restricting onshore wind energy potential, but the environmental and social constraints may have a larger impact on offshore wind energy (European Environment Agency, 2009). The OSH issues are also more demanding among offshore wind farms than onshore wind farms. However, there is a trend to move towards building offshore wind plants, which the European Commission also supports.

1.3 Wind energy turbines — onshore and offshore

Wind turbines use wind to generate electricity. The kinetic energy of the wind is first converted into mechanical energy by the rotors of the wind turbines and then into electricity, which is transferred into the grid. At present, there is a significant market for distributed power generators, whereby the electricity generated by the turbines is used or stored locally, typically by a private owner. Wind turbines tend to be grouped together in wind farms.

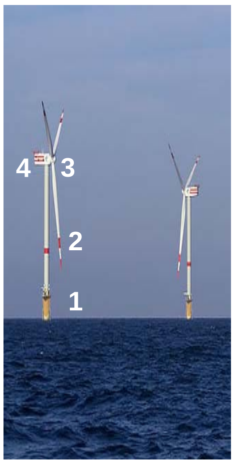
Wind turbines are installed both onshore, including inland and costal installations, and offshore, referring to those installations that are located away from the coast. Whether located onshore or offshore, wind turbines consist of similar components which can be seen in Figure 2: a tower, which rests on a substructure or foundation; a nacelle, which sits on top of the tower; and a rotor assembly, which connects to the nacelle and includes a hub to which the blades are attached and which will hold them in position as they turn. The nacelle, the 'brain' of the turbine, contains large primary components such as the main axle, gearbox, generator, transformer and control system and other mechanical components. It also contains many highly sophisticated electronic components that allow the turbine to monitor changes in wind speed and direction. These components can direct the wind turbine to turn on and off or change direction automatically in order to safely and efficiently harness power from the wind. Most commercial wind turbines have three rotor blades.

Figure 2: Common components of a wind turbine: (1) tower, (2) blades, (3) hub and (4) nacelle

Left: onshore wind turbines

Author: Leaflet

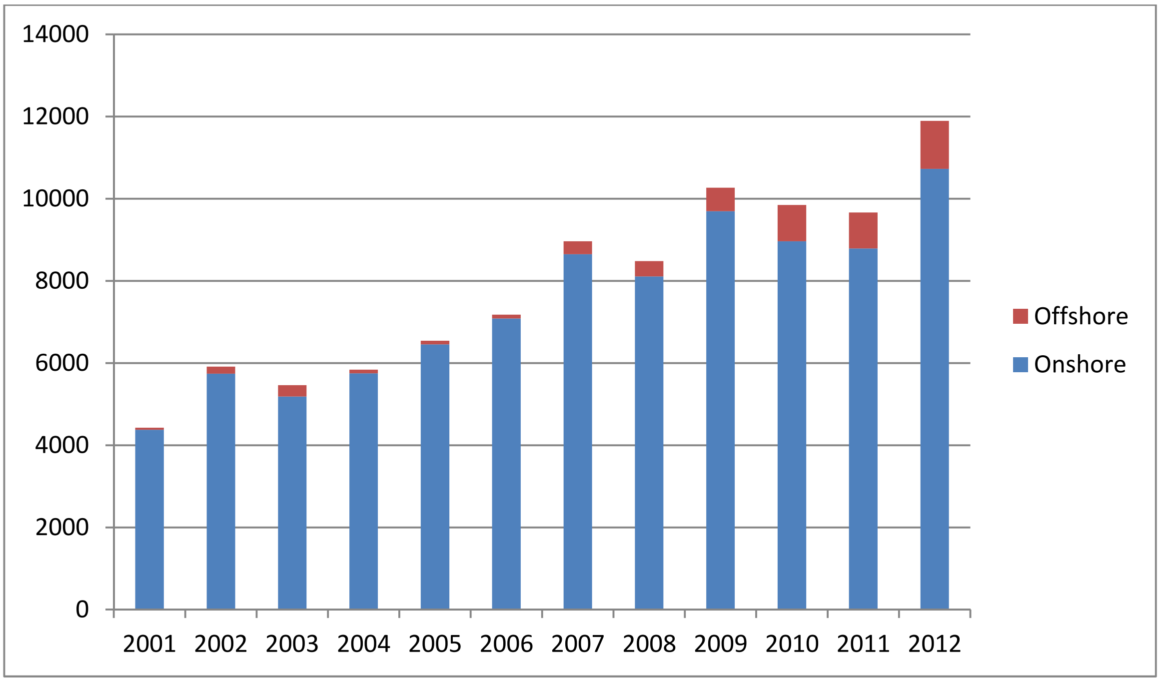
Right offshore wind turbines



Author: Hans Hillewaert

In 2011, Europe was the global leader in offshore wind energy with more than 90 % of the world's installed capacity. The EWEA estimates that around a quarter of the EU's wind energy could be produced offshore by 2020 (EWEA 2011). In the United Kingdom there are currently 267 onshore wind farms producing 3,848 MW of electricity, compared with 13 offshore wind farms producing 1,341 MW. There are a further 220 (4,756 MW) onshore wind farms under construction or consented, and 11 (3,750 MW) offshore. It is clear from these figures that, although offshore wind farms typically have larger per-farm generating capacity, onshore wind currently provides the greater proportion of wind power and will continue to do so for the foreseeable future. Figure 3: shows the annual onshore and offshore installations (MW) for Europe since 2001

Figure 3: Annual onshore and offshore installations (MW)



Source: EWEA, 2012a

Despite the similarities in the turbine components, there are large differences between onshore and offshore wind turbines that relate to cost, size and the working environment:

- **Cost**

Cost is the biggest disadvantage of offshore wind power. As with any new technology, one of the factors that determines the speed at which it is deployed and established is the cost associated with its installation, usage and maintenance. The costs for offshore wind generation have indeed been significantly higher throughout than for onshore wind farms (2.5 to 3.5 times more expensive to generate electricity from offshore wind turbines than from wind farms built on land), although recent technological improvements in the size and design of turbine technology and, in general, more efficient production patterns, may have the potential to narrow this gap. The offshore wind industry is still in a novice state compared with the relative maturity of the land-based wind industry.

- **Size**

Offshore wind turbines and farms are larger than their counterparts on land, and, as a result, the electricity production of each turbine is higher. Wind turbines are often classified as small or large. Small turbines are defined in International Electrotechnical Commission TC-88 61400 standards as having rotor-swept areas of less than 200 m^2. Standard practice also categorises small wind turbines as those that produce less than 100 kW of power. Large turbines are those that have a swept area greater than 200 m^2 and produce greater than 100 kW of power. The rotor diameter of wind turbines has increased from 10 m to around 100 m during the last 20 years. In the 1980s, the typical rotor diameter was about 10 m and generated 0.022 MW. Since 2004, a typical large turbine produces about 1.8 MW of power (3.3 MW offshore) and is about 80 m tall, with a rotor diameter of 90 m (swept area of 6360 m^2), a nominal rotational speed of 14.5 rpm and a weight of 250 tonnes. The majority of the weight, around 150 tonnes, is associated with the tower; the nacelle weighs around 70 tonnes and the hub around 18 tonnes. The blades are typically made from lightweight composites, and weigh only about 6700 kg. A recent development in the field of wind turbines is to build larger wind turbines with larger rotor diameters (European Commission, 2011a).

Lowering the cost of energy in relation to offshore wind is essential for the industry. Some of the major stepping stones in achieving this are size and subsequent increased energy capture, which means that much larger turbines that are specifically designed for the challenging offshore environment are needed. During 2012, it was expected that the 6 MW Haliade 150 wind turbine, developed by Alstom and LM Wind, would be trialled, and would realise rotor blades that extend to 150 m (Alstom, 2012). At present, each rotor blade weighs 18 tonnes, with high bending movements occurring at the inner part of the blade owing to the gravitational loads.

The size of a wind turbine onshore is subject to constraints such as the transport of components by road or of installation equipment to often remote areas. The difficulty in gaining access to some of these locations ultimately limits the size and capacity of onshore turbines. In contrast, marine transportation and installation equipment can accommodate larger and heavier components for offshore wind farms.

By 2030, the average turbine size is expected to increase to allow energy to be generated at 3 MW and 10 MW for onshore and offshore, respectively (European Commission, 2012).

- **Wind**

Wind speed is the most important factor affecting the turbine performance. A turbine starts to capture energy when the wind speed is around 3 metres per second (m/s) (Small Wind Industry Implementation Strategy Consortium) and, in general, the minimum average wind speed that is required for a wind power plant is 6 m/s. The efficiency gains achieved at higher wind speeds are significant, because the power from wind is proportional to the square (i.e. value raised to the power of two) of the wind speed. The optimum energy extraction is achieved at a wind speed of 12 m/s. If wind speed is greater than 12 m/s, the efficiency of energy capture is compromised, and if the wind speed reaches around 25 m/s there is an automatic shutdown of the wind turbine.

Wind speed can vary depending on the year, season, geographic location and terrain height. Surface obstacles such as forests and buildings decrease the wind speed. The annual variations in wind speed can be as much as 20 % (Danish Energy Agency, 2009; European Commission, 2011). Offshore wind is typically less turbulent than wind onshore, but average and extreme wind speeds are often higher than those on land.

- **Working environment**

The working environment differs significantly between offshore wind farms and those on land. Working offshore in a marine environment is challenging and introduces multiple hazards not experienced onshore. This could entail working on the water in or with a boat, or under the water in diving operations. Furthermore, weather conditions offshore can be harsh and will change constantly, and this increases the risks to workers when they are assembling or maintaining wind farms or being transferred to and from turbine platforms by vessels in shifting seas.

- **Other factors**

There are other factors that can cause significant challenges for onshore wind power projects, but which are considered less problematic offshore; for example, proximity to people, noise, visual impact and cultural heritage. The fast growth of onshore wind farms in Europe has led to a situation where the best locations to build a wind farm onshore are already in use; however, space constraint at sea is not an issue.

2 Method

The researchers used a desk-based method to source the information and data used in the report. They decided on the inclusion and exclusion criteria to determine the data to be used. In order to be included, the information and data had to (i) relate specifically to the health and safety of workers within the wind energy sector or the health and safety of workers in other sectors where work is carried out in difficult climates or environments and (ii) have been published within the last 10 years. During the search for relevant data, the researchers found a significant amount of information on company websites that provided useful background information on the wind energy industry. However, the potential commercial bias of this information meant that much of it had to be discounted from the initial sift when reviewing documents and then for classification into the database that was used to record the extracted information.

The documents were ranked as listed below, that is articles from peer-reviewed journals rated as the most robust research:

- peer-reviewed journals;
- government reports and non-governmental organisations;
- trade associations and trade unions;
- newspapers and magazines; and
- pressure group information.

Owing to the shortage of papers that refer specifically to OSH issues within the wind energy industry, the researchers used their discretion in deciding which documents to include or exclude. Moreover, if the researchers felt that the data presented were not very robust, they were not included in the report.

The researchers devised search terms for the review. After several refinements, the researchers decided on the following primary search terms:

- Onshore wind energy
- Offshore wind energy
- Onshore wind farms
- Offshore wind farms
- Renewables or emerging energy technologies

The search terms were used in combination with other relevant ones in order to retain focus on OSH issues likely to be faced by the wind energy sector both on- and offshore at different phases of the life cycle. A list of the terms used can be found in Appendix 1.

The resources included those available on the Internet that were found through Google and Google Scholar search engines; the grey literature; and Ebsco, Oshrom, Oshupdate, Proquest, Science Direct, Web of Science and STN research databases. In addition, the European Agency for Safety and Health at Work (EU-OSHA) provided access to its network of national focal points ([1]). Information was received from 10 Member States (Austria, Denmark, Germany, Finland, France, Ireland, Lithuania, Norway, Slovakia and Spain); this included anecdotal observations from these countries' experience of the industry and links to peer-reviewed journal articles and wind energy industry trade bodies.

This use of grey literature ([2]) allowed reports and research output which may not have been covered during regular searches of electronic databases to be assessed, thereby allowing a broader, more comprehensive assessment of the various topics under discussion.

([1]) The focal points are nominated by the government in each of the Member States as EU-OSHA's official representative in that country. The focal points are typically the competent national authority for safety and health at work. Each focal point manages its own tripartite network consisting of government bodies and representatives from worker and employer organisations (http://osha.europa.eu/en/oshnetwork/focal-points).

([2]) Grey literature is authoritative primary scientific report literature in the public domain, often produced in house for government research laboratories, university departments or large research organisations, yet often not included within major bibliographic commercial database producers.

The data in this report, while mainly EU focused, include research from outside the EU to supplement the information and practices in this area to ensure that the most relevant data have been accessed and assessed for their relevance to the topic.

The researchers systematically captured the key information in the documents in line with the objective of the research. General summaries were used to capture key points from the articles.

The short descriptions of good-practice examples included in this report were found partly through EU-OSHA's focal points, desk-based research and any contacts the authors might have had from within the industry, including trade associations.

3 General OSH challenges in the wind energy sector

The wind energy sector is still relatively new, with wind turbine technology constantly progressing in tower design and component technology. These modifications create an on-going responsibility to ensure that workers who conduct installations, routine operations and maintenance procedures on wind turbines do so under the safest possible conditions. The existing fleet of wind turbines is relatively young and manufacturers tend not to publicise failure data; therefore, the amount of available information is sparse. It could be argued that the hazards found within a wind farm are not too different from those that exist in other industries today (e.g. falls from height, manual handling). However, considering the sometimes unique and extreme conditions in which these hazards are found (e.g. isolated, remote and difficult-to-reach areas and extreme weather conditions), the new combination of these hazards and the inexperience of some of the workers in this sector, it is possible that these hazards may not be controlled or managed appropriately (EU-OSHA, 2013).

Over the past few years there has been an upwards trend in the number of accidents occurring in the wind energy sector. Simply put, as more turbines were built, more accidents occurred. The Caithness Wind Farm Information Forum (CWIF) (CWIF, 2013) gathers worldwide information on wind turbine-related accidents, which is found through press reports or official information releases. These reports provide a cross-sectional assessment of the types of accidents that occur and their consequences. Since 1970, the total number of accidents has reached 1,370, but most of these occurred over the last five years. On average, there were 141 accidents per year from 2008 to 2012, and, in 2013, by 30th September, 112 accidents had occurred. Since 1970, 104 fatal accidents have occurred causing 144 fatalities, and, of these, 87 deaths were among support workers within construction, maintenance and engineering or among small turbine owners and operators. The remaining 57 fatalities involved members of the public or individuals in some way not directly linked to wind energy production, including, for example, transport workers. A total of 99 accidents have caused human injury to wind industry or construction and maintenance workers, while 23 further accidents have caused injuries to members of the public or workers not directly involved in wind energy production, such as fire fighters and transport workers. Since 2012, CWIF has also included human health incidents in its statistics. These incidents include, for example, turbine noise and shadow flicker. There were six incidents impacting on human health in 2012 and 24 up to 30th in 2013. Such reports are predicted to increase significantly as more turbines are built.

CWIF believes that its compendium of accident information is the most comprehensive available, but stresses that it may represent only 9 % of actual accidents. Accident data in the wind energy sector are hard to find and usually the information available is not very comprehensive. Some national wind energy associations do publish accident statistics, and these data confirm that there are more accidents within the wind energy sector; the information provided by CWIF is only the ‘tip of the iceberg’ in terms of numbers of accidents and their frequency.

Examples of accident data collection at Member State level

RenewableUK: In 2006 RenewableUK formed a lessons-learnt database to record details of accidents, incidents and near-misses across the wind energy industry in all phases of a project from design and construction to operation. Data are provided to the database by RenewableUK members on a non-attributable basis. The full database is available in confidence only to members, although a publicly available summary of the data is published annually. The confidential nature of the database encourages incidents to be reported by members. In 2011, RenewableUK suggested that around 1,500 accidents and other incidents had taken place on wind farms between 2007 and 2011. This included four deaths and a further 300 injuries to workers.

In 2013 this lessons-learnt database was replaced by the Renewable Industry Safety Exchange system (RISE; http://www.renewablesafety.org/). RISE is a sector-led initiative to facilitate the collation, sharing and dissemination of health and safety incidents, events and emerging industry learning and good practice.

Asociación Empresarial Eólica — Spain wind energy association: This information is collected from participating companies, the number of which increased from 12 in 2007 to 40 in 2012 (AEE, 2013).

It should be noted that comprehensive, reliable data on accidents are scarce at the EU level; this is **even more so for data on work-related or occupational diseases in occupations related to wind** energy.

3.1 Skills shortage

Considering that the core parts of the wind energy sector are around only a decade old, experts, or a workforce of any size, are still thin on the ground. Even though there has been an influx of workers to the wind energy sector (from 2007 to 2010, jobs in wind energy grew by nearly 30 % while EU unemployment rose by 9.6 % – (EWEA 2012c), many of them are inexperienced in the field. The rapid development of the sector is creating severe skills shortages (trained and experienced workers especially in operation and maintenance activities) to the extent that a TP Wind report claims that there is a shortage of around 5,500 appropriately qualified staff per year. This shortfall could climb to 28,000 by 2030 — nearly 5 % of the entire wind energy industry workforce — if the number of suitably skilled workers does not increase and existing skills are shifted in the wind energy sector.

The existing skills gap falls within two levels: first, the professional level, including project managers and engineers, and, second, the operational level, which consists of staff such as vessel crew members and electricians. Over the next few years the ratio of operational to professional workers will increase as the industry moves from the design and build phases to the operational phase.

The lack of an industry standard in practical wind energy training is seen as one of the major factors attributing to this skills gap. According to RenewableUK, although there are generic (not specific to wind energy) onshore and offshore health and safety standards available, outside of this it is left to each individual wind energy company to interpret what is an adequate standard. Small and medium-sized companies are not able to afford to offer training to potential workers, which makes it difficult for them to have skilled workers. Even larger companies, which can afford to provide such training, could benefit from a common training standard, and the time and money they invest in bringing new recruits up to standard could be used to expand other parts of the business.

There are many professionals from other industrial sectors who could be trained to utilise their qualifications or transfer their skills to the wind energy sector (e.g. transferring the skills of those working in offshore oil and gas to the wind industry, as the two share much synergy) and this would contribute to developing a competent, professional and well-trained workforce. Still, wind energy-specific training would enable the transition of technical skills to the needs of the wind energy industry.

The wind energy industry is trying to provide workers with the requisite skills and knowledge that will allow them to work safely by establishing their own training programmes — although it is recognised that more should be done (Global Wind Organisation, 2012). Henning Kruse, the chairman of TP Wind, called for the support of research institutions and universities from the EU and the Member States to establish education programmes for the industry (Global Wind Organisation, 2012). Recommendations from 'European wind energy training needs, opportunities and recommendations' reports included the need to increase industry input into academic courses, harmonise vocational education and training across the EU and place greater emphasis on training in operation and maintenance.

One training recommendation (Duff, 2010) is that, as a minimum, wind energy workers should receive training on:

- competent climber/tower rescue;
- general industry or construction safety (OSHA,) (wind specific, if possible);
- first aid, including cardiopulmonary resuscitation and automated external defibrillation;
- electrical and electrical metering safety;
- metering equipment practical evaluations;
- mechanical safety;

- torque equipment and other tools of the trade; and
- crane signal and rigging practices.

The Global Wind Organisation (GWO) has also been working on an initiative to develop a common training standard for the wind energy sector. This consisted of 16 of the main actors in the offshore wind energy sector. The result of this work has been the development of a standard for basic safety training. This basic training covers first aid, manual handling, working at heights, fire awareness and offshore sea survival ([3]).

Training at national level has also been developed to enhance the basic skills and knowledge of anyone working in the wind energy sector. As an example, RenewableUK, in consultation with members and key stakeholders, has developed industry training standards, such as working at height and rescue and marine safety training ([4]).This training is, of course, compatible with the respective GWO standards.

In the coming years the industry will see a number of scenarios regarding the skills gap. The best scenario will be that a new workforce emerges from training schemes and a transfer of skills from other industries. For now, the hope is that the current collaborative attitude of those involved can attract enough people to support the operations of such a rapidly advancing chance for clean energy provision.

Working at height and rescue training – Wind turbines

The objective of the *working at height and rescue training standard* (RenewableUK) is to ensure that all personnel operating in the wind energy sector are able to demonstrate a common level of basic competency for working at height and rescue within a wind turbine. This standard sets out:

- the syllabus and arrangements to deliver basic training and competence assessment for work at height and rescue by an approved training provider; and
- the syllabus and arrangements to deliver refresher, repeat training, and competence assessment for work at height and rescue by an approved training provider.

In the syllabus, relevant health and safety legislation and hazards and working at height activities (including working at height equipment and working at height emergencies) are covered. The optimum contact time for this training and assessment is seen as 16 hours. It is recommended that the ratio of 25 % theory to 75 % demonstration and practical activities is appropriate to deliver and assess all modules. The specific need for additional training is dependent on the nature of the work at height that may be performed and the specific design or configuration of a turbine. In particular, this standard does **not** address the specific training and knowledge requirements for hub rescue or rescue within blades; safe working at height and rescue associated with lifts in turbines; safe working at height and rescue associated with climb assist and associated technologies; safe working at height and rescue for turbines where primary access to the nacelle is external to the tower; and any other situation with the potential for work at height or rescue in a wind turbine which involves more complex or extreme hazards or operational circumstances

Source: Renewableuk (2010a)

3.2 Procedures and standards

Health and safety practices in the young but growing offshore wind industry have suffered from a lack of international consistency. Until recently, the development of any OSH guidelines and practices outside individual projects or businesses was very much up to the industry itself, with companies tailoring their approach to individual countries and projects. Nowadays, European turbine manufacturers, developers, operators, trade associations and other interested parties are developing a more unified approach to better meet OSH challenges. This includes sharing incident data,

([3]) http://www.ewea.org/policy-issues/health-and-safety/gwo-standards/
([4]) http://www.renewableuk.com/en/our-work/health-and-safety/training/index.cfm

responding to government proposals for changes in OSH legislation and agreeing on consistent European standards for safety training. The promotion of best practice and harmonisation of OSH regulation, standards, training, safety rules, documentation of work and so on is seen as vital to reducing risks to workers involved in the wind industry.

Table 1: **Breakdown of the wind standards by category and number**

Category	Total	Performance	Product	Pre-installation	Installation	Testing, sampling and analysis	Cross-cutting
Wind	39	2	14	7	2	11	3

Source: International Renewable Energy Agency, International Standardisation in the Field of renewable Energy (IRENA 2013)

As can be seen in Table 1, the number of wind turbine standards (39) is considerably lower than for other technology groups, for example photovoltaic (149), solid biofuels (139), hydro (61) and solar energy (41). In addition, there are no standards that address general issues, certification, operation, manufacturing, sustainability or training skills and qualifications.

Wind turbine standards need to address design requirements as well as cover associated components, systems and technologies that have an impact on the reliable functioning of wind turbines. Despite the increasing amount of wind-related experience, there has been little or nothing in the way of published OSH guidelines or standards. ISO 9001, ISO 14001 and OHSAS 18001 provide general guidance with regard to quality management, OSH and environmental management, but there are currently very few standards that specifically address the unique needs of the wind energy industry. One of these existing standards is the IEC 61400 series, which gives a set of design requirements that aims to ensure that wind turbines are appropriately engineered against damage from hazards within their planned lifetime. It provides the requirements for all aspects of the design, build and operation of an offshore wind farm. This series covers topics such as:

- IEC 61400-1: Wind turbines — Design requirements
- IEC 61400-2: Wind turbines — Design requirements for small wind turbines
- IEC 61400-3: Wind turbines — Design requirements for offshore wind turbines
- IEC 61400-3-2: Wind turbines — Design requirements for floating offshore wind turbines
- IEC 61400-4: Wind turbines — Design requirements for wind turbine gears
- IEC 61400-5: Wind turbines — Design requirements for wind turbine rotor blades
- IEC 61400-11: Wind turbines — Acoustic noise measurement techniques
- IEC 61400-12: Wind turbines — Wind turbine power performance testing
- IEC 61400-13: Wind turbines — Measurement of mechanical loads
- IEC 61400-14: Wind turbines — Declaration of apparent sound power level and tonality values
- IEC 61400-21: Wind turbines — Measurement and assessment of power quality characteristics of grid connected wind turbines
- IEC 61400-22: Wind turbines — Conformity testing and certification
- IEC 61400-23: Wind turbines — Full-scale structural testing of rotor blades
- IEC 61400-24: Wind turbines — Lightning protection
- IEC 61400-25: Wind turbines — Communication protocol
- IEC 61400-27: Wind turbines — Electrical simulation models for wind power generation

One important legislative development in the wind energy industry is the planned update to the European wind turbine standard EN 50308 (Wind turbines — safety requirements for design, operation and maintenance). This revision is still on-going but it is expected that, for the first time, it will take proper account of offshore facilities and cover everything from turbine erection, access hatch sizes and machinery guards to emergency escape lift requirements and lighting. The need to perform risk assessments will also become more explicit. The clarification or introduction of these new turbine-specific safety measures will assist in ensuring that safety is considered from the start of the turbines' life cycle.

To be able to keep design and production reliable and conducive to the long-lasting use of wind turbines, so that they may remain dependable in service for the duration of their planned lifetime, these standards need to be further complemented by efforts from ISO and other national standard bodies. The National Institute for Occupational Safety and Health (NIOSH) organised a workshop in 2009 entitled ‘Making green jobs safe’, as part of its Prevention through Design initiative. This was attended by 170 representatives from OSH and environmental communities within industry, labour, academia, government agencies and non-government organisations, who discussed the occupational hazards and risks associated with green jobs. One of the main issues that the workshop highlighted was the need for consistent standard codes for the entire life cycle of wind turbines.

International associations such as the European Wind Energy Association (EWEA) are also working towards the promotion of best practice and harmonisation of OSH regulation, standards, training, safety rules, documentation of work and so on within the wind energy sector. This is seen as vital and necessary to reduce risks to workers. EWEA will be publishing new health and safety guidelines on emergency arrangements including first aid. These guidelines will cover both onshore and offshore facilities and are suitable for all EU countries, as they are based on European regulations. This document aims to serve as a general guidance, and applicable regulations for individual countries should be consulted as they may include additional requirements. These guidelines highlight the importance of incorporating OSH into the design stage of the wind farm; having the necessary arrangements and provisions relevant to the activities on site; inspection and maintenance; measuring performance; and reviewing and auditing in order to improve.

At the national level, trade bodies are also working to improve standards within the industry by producing best-practice OSH recommendations and guidelines. For example, RenewableUK (2010b, 2013) has published a number of guidelines and organised two accredited training courses, which have become standards in the United Kingdom. Its OSH forum is the main UK intermediary between the Health and Safety Executive and the industry.

Finally, the largest offshore wind developers have also seen a need to come together and form a new group that places OSH at the forefront of all offshore wind activity and developments: the G9 Offshore Wind Health and Safety Association (known as G9) ([5]). The primary aim of the G9 is to create and deliver world-class health and safety performance across all of its activities in the offshore wind industry. In order to achieve this aim, senior executives of the G9 member companies have committed resources from their own company teams, and have also met under the auspices of the G9 board to actively lead the industry in finding solutions to the safety challenges that offshore wind

([5]) http://www.energypublishing.org/g9/about-the-g9 projects face. The founder member companies of the G9 are Centrica, DONG Energy, E.ON, RWE Innogy, Scottish Power Renewables, SSE, Statkraft, Statoil and Vattenfall. To take the G9 leadership ambition further, a work programme aimed at reducing the risks in the offshore wind industry has been initiated. To deliver on this work programme, the G9 has partnered with the Energy Institute and established three work groups to develop good-practice guidance publications for the offshore wind industry on working at height, lifting operations and marine vessel operations.

Lifting operations: Lifting operations, both heavy lifting and more routine smaller lifts, are an intrinsic part of offshore construction and present a potential risk for the offshore wind industry during the construction phase of a wind farm. Through this publication, the G9 is seeking to define, understand and mitigate potential risk exposure in the industry when undertaking lifting operations.

Marine operations: The G9 is looking to develop guidelines and requirements for the management of service vessels used in the offshore wind industry, in order to ensure compliance with regulatory requirements and good operational practices. These guidelines will reference good practice available in the offshore oil and gas sector and will take account of and reflect the unique aspects of working in the offshore wind industry.

Working at height: The G9 is looking to steer the development and publication of technical and operational guidance to be implemented in the offshore wind industry to mitigate the risk of working at height. The guidance will provide a high-level overview of current working at height operations, and will reference operational guidance that has been developed for the offshore oil and gas sector. Guidance will be provided for a number of high-risk working at height operations.

3.3 Gender aspects in the wind energy sector

Mature and blooming as it is, the European wind energy industry remains overwhelmingly male. There is very little mention of women in the wind energy industry other than in relation to the manufacturing process (Ponten, 2004; Rasmussen, 2005; Safety and Health Practitioner, 2009, Health and Safety Bulletin, 2009. Although there are women holding a range of posts within the wind energy industry (e.g. Women of Wind Energy in Germany ([6])), there are currently only a handful opting to work as wind turbine technicians. There is no evidence to suggest that women cannot cope with the physical and psychological demands of working on wind farms or that women with relevant qualifications might be excluded from, or self-exclude themselves from, fieldwork within the wind energy industry.

A number of women working in the wind energy sector were interviewed for an article in the EWEA's *Wind Direction* magazine. The article, 'Where are the women in wind?', notes that none of the female interview subjects complained about her job; they all agreed that the sector had been a good and nurturing fit for them (Rose 2010). It is possible that some of the barriers to encouraging more women to enter the industry include the long hours, travelling distances and, to some extent, welfare provision. In the USA, the Women of Wind network has met since 2005, and provides mentoring and advice on careers for women who are already working within the industry or thinking about wind energy as a career. In Germany, where the wind energy industry is well established, women employed within the industry have set up a Women of Wind network to promote the role of women at all levels. The extent of this network's influence on the industry and whether it will lead to more women taking up technical and engineering jobs with onshore and offshore wind remains to be seen.

([6]) http://www.womenofwindenergy.de

3.4 The ageing workforce

No literature was found on ageing workers in the wind energy sector. Some of the occupations within the wind energy sector are physically demanding, especially those that require climbing ladders in high wind towers or working in confined spaces for long periods of time, both of which may impact on health and may in turn affect the workability of the older worker.

Although not completely transferable to the wind energy area, information from the oil and gas industry may prove useful, particularly with regard to offshore work. For example, the BARD offshore project in Germany took over 3 years to be constructed and is located 100 km (62 miles) from the coastline, which means that transportation of workers takes 18 hours. For this reason, workers normally spend 14 days offshore on accommodation platforms and 14 days at home during the construction and installation phases. In these situations, transfer of information from the oil and gas industry is possible.

Older workers operating in the North Sea oil and gas industry (Parkes, 2002) reported poor sleep and had a higher body mass index. Poor sleep is associated with increased incidence of cardiovascular disease and diabetes, and lack of sleep may increase the likelihood of concentration lapses. However, they also reported greater satisfaction with work tasks and job prospects than those in the middle age ranges. Job satisfaction is linked with lower levels of stress.

Although there is no evidence that work performance, even in physically demanding jobs, is directly related to age, there is a number of factors that can impact on an individual’s ability to carry out a job, including job satisfaction and job prospects. Employers therefore need to treat every worker on an individual basis regardless of their age, and to take into account the specificity of each worker in the workplace risk assessment in order to ensure that the job demands are consistent with the abilities of the worker (Department of Health and Human Sciences, 2009).

Experience in the oil and gas industry has shown that older workers may tend to self-select themselves to retire or move to onshore working if working offshore becomes an issue for them. The self-selection may mean that it is not possible to get a true picture of the characteristics of older workers offshore, as the remaining personnel will be healthier.

3.5 Work organisation and psychosocial risk factors

There is little written about the psychosocial aspects of working in the wind energy industry. The closest comparisons can be made with the oil and gas industry, particularly in research related to workers offshore and sited in stabilised accommodation platforms. However, some degree of caution needs to be taken, as they are different industries with a variety of different occupational hazards, as can be seen from section 4 of this report.

Still, the following key psychosocial risk factors identified in a report about workers operating in the North Sea oil and gas industry (Parkes, 2002) also apply to workers in offshore wind farms:

- Personnel working day/night rotating shifts were more likely to report sleep disturbance and gastric problems than those working only day shifts.
- Injuries that occur during the night shift tend to be more severe.
- Day/night shift workers were more likely to visit the installation sick bay than day workers. They were also more likely to visit the sick bay because of an accident.
- Fixed shift patterns are less likely to cause problems with sleep, alertness and performance than rollover patterns.
- Working long hours both onshore and offshore adversely affects mood and performance, but the offshore environment tends to intensify the issue.

Lone working, or working remotely for extended periods, also needs to be considered when assessing psychosocial risks.

Owing to the remote location of some wind farms and environmental factors, such as extreme weather conditions, project managers and supervisors need to carefully plan the provision of suitable welfare facilities. Workers on wind farms located in remote and exposed regions should be provided with an area where they can go to keep warm or cool down and hydrate, especially if toilet facilities have not been built into the actual design of the turbine. Such welfare arrangements should be in place for both onshore and offshore wind farms, and should extend not only to the workers engaged in the installation, maintenance and repair of wind farms, but also to drivers taking components to onshore locations or to port for offshore installation.

Work organisation should also consider the requirements of workers who work at height for several hours at a time, either in harness or confined within the nacelle. Depending on whether lifts are available or in operation, the logistics involved in returning to 'ground level' may make it more practical for breaks to be delayed, as accessing and leaving wind turbines may expose workers to risks including falls from height, slips, trips and musculoskeletal disorders. If this is the case, workers should ensure that they take water and other refreshments with them so they can keep hydrated.

Project managers and supervisors can create a good health and safety culture by acting as role models for good health and safety behaviours and taking a lead when it comes to controlling risks through good management and planning practices.

The literature contains discussions on the measures that should be taken to control risks (RenewablesUK, 2010b, 2011b); Atkinson, 2010; Cook, 2011; Spinato, 2009) Industry guidelines in the United Kingdom (RenewablesUK, 2011b,) call for management to be proactive in maintaining '*a strong health and safety culture from the outset'* including a full site safety management system, and this is replicated in a number of other documents from the United Kingdom (Cook, 2011; Clarke;.Spinato, 2009).

Other suggestions found in these documents include:

- holding meetings prior to work being undertaken, so that a job safety analysis can be carried out and critical lift reports assessed;
- working in pairs or larger groups;
- ensuring that every worker has the knowledge, skills and experience to carry out the tasks expected of them (Rodrigues et al. 2009);
- carrying out fitness to work assessments of workers (Rodrigues et al. 2009); and
- carrying out risk assessments and ensuring that 'site rules' are developed that take into account contractors and visitors, as well as workers.

Subcontractors are widely used within the wind energy industry. There may be, for example, more than 500 workers, including many subcontracted workers, working at the same time on the construction site of a wind farm. All workers, including subcontracted workers, should be suitably skilled and have received adequate training and work instructions to perform their work safely. The workplace risk assessment should include all workers, including all subcontracted workers, in order to guarantee good work coordination and organisation, adequate communication and safe working conditions.

Owing to the remote locations of wind farms, some companies are adapting existing risk assessments. Although by no means representative of the rest of the wind energy industry, it is useful to illustrate how one company has found a solution when it recognised that, because workers work on different wind farms and because of their remote location, it is more difficult to plan safety walks. The company introduced an additional level of risk assessment in the form of a plan–do–check–act (PDCA) system with 12 elements (Spinato, 2009). The PDCA system seen in table 2, allows for controls for risks and hazards to be properly planned. The company also found that this system prepares it for official certification, such as to OSHAS 18001 (occupational safety) and DIN EN 14001 (environmental protection), which it considers gives the organisation additional credibility with its stakeholders.

Table 2: **E.ON's climate and renewables 12-element plan–do–check–act system**

Plan
▪ Management commitment and credible leadership ▪ Hazards and risk management ▪ Objectives, targets and health, safety, security and environment programmes
Do
▪ Organisation and responsibilities ▪ Personnel and training ▪ Information, documentation and communication ▪ Contractor management ▪ Operational control ▪ Emergency preparedness and response
Check
▪ Incident reporting, investigating and analysis ▪ Monitoring
Act
▪ Assessment and improvement

3.6 Lack of OSH data and research on the impact of wind energy developments on workers

Over the years there has been a large number of reviews and reports that have focused on the evidence of the health and safety impacts of wind farms. These reports vary in range and depth and have been undertaken by international governments, independent scientific institutions, expert panels and supporters and opposers to wind energy developments. Overall, there is a limited amount of original scientific research, epidemiological field studies and observational and measurement studies; however, there is a large number of case studies both from the formal scientific literature and in informal public media. The one thing that all these studies have in common is that they highlight the potential impacts of wind farms on the health of local populations. The impact and effects that a wind farm development can have on public health and the environment have been widely documented, but none of these reports considers the OSH risks to which workers are exposed.

Issues such as construction and operational safety, flicker, electromagnetic radiation, noise, vibroacoustic disease and wind turbine syndrome have all been studied to determine their effect on the health and safety of people living in the vicinity of wind turbines, but the impact that these same issues could have on workers is not available.

In some countries, for example Belgium, there are regulations in place to reduce public exposure to shadow and noise from onshore wind turbines. These regulations, which have been modified recently, reduce the maximum permitted hours of shadow per year from 30 to 8 hours — with a maximum of 30 minutes per day. If a wind turbine is expected to exceed this limit, a shutdown system must be in place. In addition, the wind turbine owner has to measure and report its shadow casting for the first two exploitation years. The previous regulations considered only a 250-metre radius for noise; now noise beyond this radius is being taken into account. In addition, noise limits have been laid down with specific targets:

- Residential areas: 44 dB(A) in the daytime and 37 dB(A) in the evenings and nights
- Rural areas: 48 dB(A) in the daytime and 43 dB(A) in the evenings and nights

Despite the relative good pay, many workers stay in their job within the wind energy sector for only 3–4 years (Wind Power Engineering and Development, 2010) this is something that needs to be studied further. Considering the variety of dangerous activities associated with the high-risk wind turbine environment, more worker-focused impact studies should be undertaken.

To ensure that health and safety remains a top priority throughout the wind industry and that it continues to be seen as a safe and responsible jurisdiction in which to work and with which to do business, more research is required on the OSH implications for staff working on wind turbine projects.

4 OSH issues across the life cycle of a wind turbine

This chapter will examine the OSH risks across the life cycle of wind turbines for both onshore and offshore facilities. Hazards to workers' health and safety related to wind farm development can occur during any of the major phases of a wind farm project. The major phases of wind farm development include installation of the wind turbine; installation of cables connecting the turbines together and to the electrical grid; the commissioning of the turbine into service; the operations and routine maintenance stage; and the eventual decommissioning of the wind farm. For this report, the life cycle model used (see Appendix 2) is taken from the international standard IEC 61508 ([7]) (IEC, 2012), and will consider the following stages and activities:

- design;
- development;
- manufacture;
- transport;
- construction;
- operation;
- associated infrastructure;
- maintenance;
- repowering/life extension;
- decommissioning; and
- waste treatment and recycling.

While onshore and offshore wind farms share many hazards, the offshore work environment presents some hazards not encountered on a land-based facility. Table 3 gives a comparison between offshore and onshore wind farms of some hazards that are found in many of the life cycle stages mentioned above.

Table 3: **Examples of common hazards for both onshore and offshore facilities and those unique to offshore installations**

Hazard	Relative risk — offshore versus onshore	Comments
Personal transfers	Higher	For offshore wind farms this would involve the need for helicopter access to offshore facilities, personnel transfers between marine vessels and wind turbines, risk of collisions between vessels and wind turbines or collisions between two or more vessels operating in the same area and falls into water by personnel.
Diving	Higher	Diving operation are unique to offshore wind farms and would include hazards during foundation installation, cable laying and regular turbine inspections, maintenance and, possibly, decommissioning.

([7]) IEC 61508 is an international standard of rules applied in industry known as functional safety of electrical/electronic/programmable electronic safety-related systems.

Hazard	Relative risk — offshore versus onshore	Comments
Emergency evacuations	Higher	Evacuation from offshore wind turbines during a fire, explosion or severe weather conditions are more difficult. In addition, there is also the travel distance to and from shore during emergencies that needs to be considered.
Exposure to weather conditions, heat and cold	Higher	Offshore work is subject to more extreme weather conditions. This may result in time pressure for offshore workers to perform the work, as they have to comply with tight time constraints that can easily be deflected by changes in weather or shipping delays. In addition, offshore facilities have limited possibility for climate-controlled spaces. As a result of changes in weather conditions, workers on offshore facilities can end up stranded on wind turbines for days
Structural	Higher	Structural failures intrinsic to the marine environment, such as wave action, currents and corrosion, will affect components. These are not present in onshore wind farms.
Crane lifts	Higher	Although the basics of lifting operations are the same onshore and offshore, the following make lifting offshore more difficult: ▪ offshore turbines are larger so entail lifting of larger components (loads); ▪ more extreme weather conditions, e.g. greater wind loads; ▪ movement of the vessel during lifting; ▪ limited working area on the vessel; ▪ motion of the turbine (floaters); ▪ lifting on occasions done over the boat deck.
Falls from heights	Similar	Personnel working in the tower of the nacelle both onshore and offshore are at height and climb ladders many times a day, and they face fall hazards or exposure to dropped objects.
Confined spaces	Similar	For offshore and on land turbines, once the technician is inside the wind turbine, most tasks are exactly the same. Thus, for the majority of tasks inside a wind turbine, the hazards and risks are similar. In a wind turbine, workers encounter confined spaces, with related hazards such as poor ergonomics/awkward postures and exposure to fumes, dust and toxic chemicals and materials.

Hazard	Relative risk — offshore versus onshore	Comments
Awkward postures	Similar	Workers confront awkward postures, prolonged kneeling and repetitive upper body movements, often in cramped spaces, which can lead to short-term sprains and fatigue, as well as long-term injuries.
Physical load	Similar	Both facilities require the same amount of climbing, manual handling and physical effort.
Electrical	Similar	Electrical hazards from work being performed inside the turbine are a concern for both types of facility. These would include electrical arcs and electrical shocks that can cause electrical burns and electrocution. The presence of water in offshore wind farms may complicate certain operations such as cable laying and connecting (usually done remotely).

Source: generated by author.

4.1 The importance of OSH in design and development

The more OSH knowledge and awareness is gained during the early stages of a wind farm project, the more likely the project will be to manage the implications that follow during its entire lifespan. The design process should be seen as the best place to 'design out' hazards and risks and help to prevent or minimise work-related accidents and ill health throughout the turbine's entire life cycle. Provision should be made at the design stage for the safe assembly, construction, installation, commissioning, operation, maintenance and decommissioning of the turbine. Prevention through design is a concept that requires a holistic understanding of the entire life cycle process, is applicable to all industry sectors and workplaces and is particularly relevant in the development of new technologies, processes and materials, such as in the energy sector. This is a concept that should be promoted as a cost-effective means to preventing or reducing work-related accidents and health problems and enhancing OSH within the wind energy sector.

The role of design is to provide the best foundation for the safe operation of wind turbines and to be used as a key component in the continuous improvement of future models. The rapid expansion of the wind energy sector and the ever increasing demand for clean energy has led to significant advances in wind turbine design. In the last 15 years, the size of wind turbine rotors has increased significantly. The design has to take into account the fatigue characteristics of the materials and the structural properties of the installation, as well as the types of conditions to which the rotor blades are likely to be exposed during their lifetime, such as extreme temperatures, humidity, rain, hail, impact, snow, ice, solar radiation, lightning and salinity (Kensche, 2006). Although onshore and offshore wind farms follow similar designs and share many characteristics, offshore turbines require unique features and modifications for operation in a marine environment. For example, the design of foundations and turbines needs to incorporate corrosion protection and highly sophisticated monitoring and control systems. Designs for offshore wind farms should also ensure that diving operations and other work carried out offshore are minimised by allowing as much work as possible onshore

One good example of the wind turbine's design impact on OSH is whether or not it is fitted with a lift. The ability to use a lift instead of climbing has great implications on the worker's body, in both the short and long term. This also increases the number of turbines that workers are able to climb in a certain time span, which is important from a manning perspective. The fact that the turbine itself is a tall structure adds complexity to any repairs or maintenance work being undertaken. Changing a large heavy gearbox at a height of 100 metres is quite different from a similar operation at ground level. Therefore, it is important that efforts are made at the design stage to minimise the need for working at height, facilitate good and safe access to workers in the turbine, provide sufficient working space and consider the importance of longer service intervals by minimising maintenance requirements.

Well-designed, safe turbines are essential, as safety modifications and retrofits to in-use turbines, particularly those installed offshore, may not be physically possible or reasonably practicable and can introduce significant construction risks as well as substantial costs (EERA, 2010). As an example, in September 2010 the leading provider of research-based analysis, advice and support to the global renewable power industry, IHS Emerging Energy Research, alerted that ‘at approximately 600 of Europe’s 948 installed offshore turbines, dissolved grouting had shifted turbines with monopile foundations’. The problem stems from the way in which the marine turbines are fixed to their monopile foundations. ‘These supports are not designed to transfer bending moment from wind loading. Due to the dynamic loading from the wind, fatigue cracks can initiate and propagate into the main steel structure. Retrofitting these could cost developers as much as €120,000 per turbine, equalling up to €9.6million at larger projects such as Horns Rev (Deign, 2011).

The reliable, safe and beneficial operation of wind turbines requires the use of a number of engineering safety features, much like any other engineering device. Identification of the possible failure modes under severe wind conditions, risks and hazards will lead to even more reliable and safer wind turbine designs. A number of risk assessment tools have been identified that help to identify the hazards and risks within the design. By considering OSH risks at the design stage, these tools help to ‘design these risks out’ (RenewablesUK, 2013). These tools include hazards in design (HAZID), which can be used throughout the stages of the design process to look at the failure of components and systems and to assess the consequent effect on personal safety. HAZID involves consulting experts from various disciplines about the design, so that problems can be identified and appropriate modifications made at an early stage. Other risk assessment tools mentioned in less detail include failure mode effect analysis and hazard operability study.

The design lifetime of a wind turbine is 20 years, over which it has to operate reliably and safely even in hazardous, stormy conditions. This presents a design challenge for present and future turbine designers. As a comparison, automobile engines are designed to operate for about 5,000 hours, whereas wind turbines are designed to operate with a capacity or intermittence factor of 0.4 for 70,080 hours (20 years × 365 days × 24 hours × 0.4). Long-term reliability of wind turbines is a major concern for the industry and is an issue that warrants much attention at the design stage. The majority of wind turbines currently being installed, particularly offshore, are state of the art, so their long-term in-use reliability is unproven. A number of methods to predict the service life of turbine parts are discussed in the literature. The EU Optimat Blades project (Knowledge Centre WMC, 2012), which ended in 2006, is a useful repository of data about composite materials performance, and the data can be used to develop models to predict fatigue characteristics under different conditions. Knowledge of how materials and components perform can help reduce the number of unplanned maintenance and repair visits a worker has to make to a wind turbine. In a proactive move, RenewableUK encourages wind farm operators to contact the relevant turbine manufacturers at least every 12 months to share performance information, so that manufacturers gain a better understanding of their turbine maintenance requirements.

Significant efforts are being made to improve gearbox reliability and longevity; currently, turbine gearboxes are expected to last 7–11 years, significantly shorter than the 20-year service life of the turbine (IFC, 2007; Puigcorbe and de-Beaumont, 2010). Changing a gearbox is typically a lengthy, costly and sometimes hazardous exercise, so there is much to be gained from increasing gearbox endurance. One company believes it has addressed the issue by ensuring that torque transmission is performed independently of rotor support, which reduces the load on the gearbox and other drivetrain components. No information was found to corroborate the effectiveness of these measures to increase the longevity of gearboxes. Other turbine manufacturers are producing direct drive turbines that d not turbines(8), which do not incorporate gearboxes within their design, so that the likelihood of unplanned repairs can be reduced (Raman, 2009).

Turbine reliability both onshore and offshore is a key factor in maintaining the health and safety of workers because it ensures that they have limited exposure to the potential risks and hazards associated with maintenance activities and catastrophic failures.

To further improve turbine reliability, two approaches are currently emerging:

- developing simple, robust wind turbines including as few moving parts as possible to limit the risk of failure (two bladed, downwind (9), direct drive turbines, variable speed with new generator concepts); and
- improving wind turbine intelligence, implementing redundancy, advanced control algorithms, condition monitoring and preventative maintenance (EWEA, 2009).

Wind turbine productivity, efficiency and reliability are very much dependent on the wind characteristics at any given site. Extensive research is being carried out to improve the current wind modelling techniques, so that turbine design and positioning can be optimised for any given wind farm. The European Wind Atlas aims to provide the basis for reliable estimates of the wind resources in the EU countries, on a regional scale or at a specific site (Heenan, 2012).

Furthermore, TP Wind (EWEA, 2010) is seeking ways to improve techniques for characterising wind conditions, so that turbine design can be optimised for individual sites, annual energy production can be accurately predicted and short-term forecasting of power production and wind conditions can be improved. TP Wind states it has made recommendations to enable the safe operation of offshore facilities, although it does not provide details about what these recommendations entail.

TP Wind does make a number of predictions about the developments it sees taking place in the future. These include the following:

- The present advanced wind turbine concept (horizontal axis, three-blade, variable pitch, variable speed, full-size electronic converter for maximum control) is most likely to be pursued.
- Gearbox-based drivetrains and direct drive systems will co-exist in the years to come.
- The up-scaling of wind turbines — beyond the present dimensions — as seen during the last decade is likely to continue.
- Materials with higher strength to mass ratios and compliant components will be increasingly used in the design of elements bearing heavy dynamic loadings such as rotor blades, yaw systems, drivetrain parts and towers.
- New design tools will be used to design and efficiently manufacture very large wind turbines based on significant advances in the fields of aerodynamics, aeroelasticity, control, drivetrain dynamics, etc.
- Dedicated operations and management methods and transport and installation systems will be used in extreme locations such as offshore, mountainous terrain or extremely cold climates.
- Integrated condition monitoring systems for early diagnosis and assessment of damage will be widely used to increase wind turbine availability and reduce the need for design conservatism.
- In the market segment of small wind turbines (outputs from about 1 kW to a few hundred kilowatts), a substantial improvement in technical quality will be made, leading to expansion of the market, especially in remote areas, small isolated communities and sites connected to weak grids.

Many of these developments could have the potential to improve OSH; for instance, improving the design of gear boxes and drivetrains, as well as increasing the dynamic loading capacity of components, is likely to reduce premature failures and unplanned maintenance visits, and integrated

(8) Direct drive turbines have magnets attached to the rotor, which connects directly to a generator, so a gearbox is no longer needed. Gearbox failures are one of the main reasons for unplanned maintenance visits to wind turbines.

(9) The blades of two-bladed, downwind, direct drive turbines face away from the wind at the back of the nacelle. This increases the blade lifetime and reduces the possibility of the blade crashing into the main mast.

condition monitoring is likely to reduce direct worker involvement. However, up-scaling of wind turbines may have a detrimental effect on OSH owing to the additional challenges related to the lifting, transporting and construction of large-scale components.

The offshore environment provides greater scope for larger wind turbines, and there are wind farms operating up to 20 km from shore in water depths of 20 m. Currently under construction are offshore wind farms located 60 km from shore and in waters of up to 60 m. The development of floating platform technologies is also being explored (EWEA, 2011). There are three main types of floating structures: the spar, the tensioned-leg platform and the floating jacket structure, but to date only the spar has been demonstrated at full-size offshore. It is suggested that floating structures will make for more flexible construction, installation and decommissioning. Further research will be required to assess the potential health and safety risks to operators on these types of installations (EWEA, 2011).

Although much progress has been made, concerns are being raised about some aspects of wind turbine design. It has been suggested that the design of wind turbines has not fully taken into account the risks associated with the flammability of the nacelle and rotor, and that a single point of access to the nacelle area is insufficient. In an attempt to address these concerns, Siemens introduced a steel cover, so that the nacelle will not burn easily. Further proposed design features include secondary escape routes — one inside and one outside the tower (Kensche, 2006).

Concerns have also been raised regarding the suitability of the lifts that are currently being installed in many tall turbines. There is currently no European standard for turbine lifts and, although the benefits of providing lifts are acknowledged, it is suggested that the lifts currently being installed do not comply with the requirements of Directive 2009/104/EC (Use of work equipment). Even though it is claimed that these issues can be overcome using physical or procedural interventions (RenewableUK, 2011b) the issue of elevators in wind turbines has been discussed at the European level. Meetings between wind turbine industry stakeholders and authorities have taken place, where discussions and appropriate agreements were reached on a number of issues specifically relating to vertical transport carriers installed in larger wind turbines. A meeting held in June 2012 by the ad hoc working group on vertical transport in wind turbines concluded work begun in 2010 when authorities carried out visits to installations examining conformity to the then revised Machinery Directive (2006/42/EC). Initial matters of concern were presented to industry stakeholders in Hadsten, Denmark, in July 2010. A paper with the findings was presented to the Administrative Co-operation Working Group meeting of the Member States' authorities in summer 2012. The points raised and opinions of the participants in the meetings and presented in the paper were not be considered as a 'standard'; however, Member States' authorities and economic operators should take them into account when considering the 'state of the art' for carriers within large wind turbines. The European Commission has requested that information on this topic be shared widely. This document was shared with the machinery working group for consideration in their first meeting of 2013. Some of the issues identified are shown in Table 4.

Table 4: **Examples of conclusions and observations made at the meeting of the ad hoc working group on vertical transport in wind turbines**

Issue	Conclusion
Height of turbine where 'lift' should be installed	All turbines ≥ 60 m to be provided with a lift. Turbines < 60 m to be provided with a lift where practicable; climb assist systems could be considered, but should not replace the provision of a lift where practicable. Guides and means to suspend traction ropes must take account of turbine dynamics and movement. The travel zone of the lift should be maximised to reduce ladder use as far as practicable.
Interlocking of landing gates with carrier	Interlocking of components to ensure that gates cannot open when the carrier is not present must be provided.

Issue	Conclusion
	Over-ride for landing gates can be provided for emergency situations; this should not over-ride carrier door interlocks. Where interlocking is achieved, self-closing gates are not mandatory.
Locking of carrier doors	Door-locking system to accommodate three possible scenarios: 1. Normal use — door interlocked with carrier movement to prevent door opening when carrier is between landings. 2. Observation required between landings — it is preferable to have an opening or window in closed carrier door to maintain fall prevention. Unacceptable to rely on personal protective system (harness-based system). 3. Access between landings (maintenance or emergency) — facility to override carrier gates interlock should not interfere with landing gate interlocks.
Mechanical hazards in travel zone	Speeds of up to 0.25 m/s are now achievable. Any protective devices should take this into account. At ‘base’ platform, it is accepted that a full height barrier may not be appropriate. Intermediate (non-working) platforms — a barrier is required for fall prevention but an infill is not normally necessary. Top platform (and base where provided) barrier to be provided with infill to prevent body parts entering travel zone. Where other shear or crush hazards exist (where there is potential for persons to enter the travel zone) then ‘trip’ plates or mechanisms are to be provided.
Emergency stops	To be provided where carrier control stations are positioned. To be identifiable as relating to carrier only, positioned appropriately in relation to carrier controls and travel path. Must be provided at base platform; recommended at top platform. Provision at intermediate platforms may not be necessary.
Emergency rescue from carrier	Manufacturer’s risk assessment must take account of person in lift incapacitated, with no power and in extreme cases with problems with suspension or guide ropes. Preferable to leave casualty in carrier and bring carrier to ground where possible. If controls on lift are accessible from a ladder, without significant risk, then this is acceptable. Where carrier controls are not accessible, then remote control is necessary. In either case, specific emergency procedures must be developed and provided to users.

Source: Informative note of the meeting of the ad hoc working group on vertical transport in wind turbines, 15–16 June 2012.

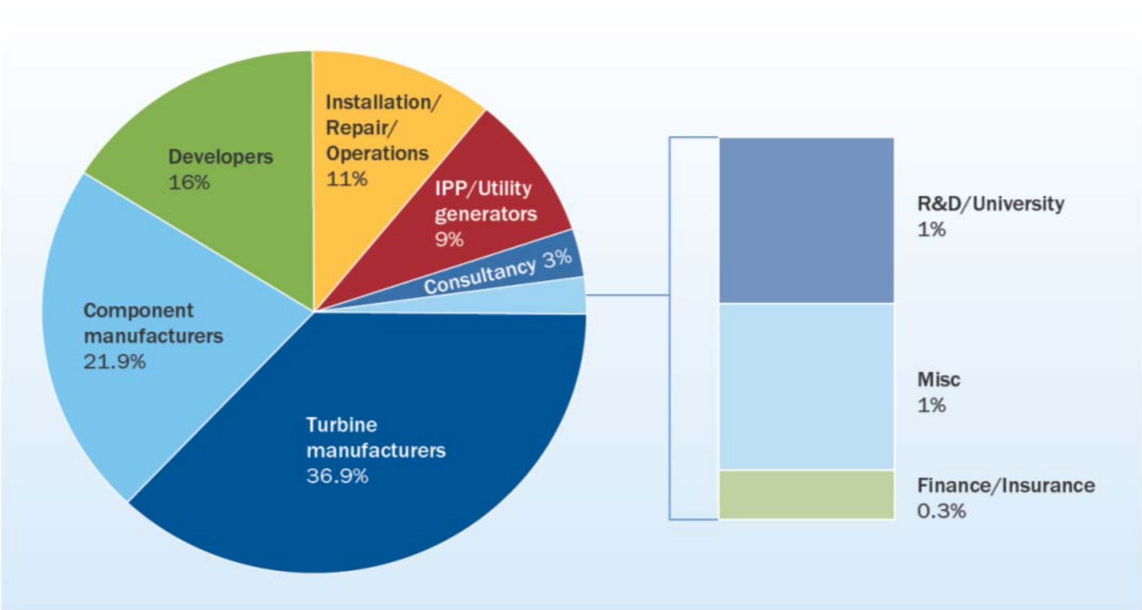
In the EU, there is currently extensive research being undertaken in the field of wind energy, with more than 80 % of the long-term research being carried out by the EWEA, which includes 27 institutes in seven EU countries (EWEA, 2010; EERA, 2010). Although OSH in itself does not feature prominently in the current research plan, some of the areas of research are bound to influence it. In 2006, within the European Commission, a five-year EUR 22,340,000 EU-integrated project was initiated to develop improved design models and verification methods for wind turbine components. The European Commission funded the project, which involved 11 EU countries, numerous research institutions and a variety of stakeholders (EERA, 2010).

Developments in other industries also have an impact on the wind energy sector; for instance, recent developments in paint technology have provided an easy means of assessing the condition of painted surfaces. The new ‘smart paint’ conducts electricity via carbon nanotubes and its conductivity is affected by cracks in, or corrosion of, the painted surface (The Economist Technology Quarterly, 2012). An assessment of the condition of the turbines’ painted surface can therefore be carried out remotely, based on conductivity readings, so that some of the need to work at height can be avoided. Although this paint may help to solve one problem, it may introduce others; a recent study suggests that inhaling some types of carbon nanotubes could be seriously harmful to health and lead to asbestos-like effects (Donaldson et al., 2010). This example demonstrates how the OSH implications of new designs and technologies have to be carefully considered before they are used.

4.2 OSH risks associated with the manufacture of wind turbines

In 2009 EWEA provided a valuable breakdown of wind energy employment type by jobs, as can be seen in Figure 4. This breakdown shows that the engineering areas of wind turbine manufacturing, component manufacturing, installation, repair and operations accounts for 70 % of all employment in the industry. The manufacture of wind turbines and its components on its own accounts for 58.8 % of all workers.

Figure 4: Breakdown of wind energy employment by type of job



Source: Fitch-Roy, 2013

Wind turbines consist of three major components — blades, tower and nacelle (Figure 2) — each of which has to be designed and produced separately.

Wind turbines are large, complex pieces of machinery, and the International Labour Organization recognises that their manufacture presents hazards that are similar to those in the car and aerospace industry. As with any similar heavy engineering industry, workers will be exposed to a range of hazards associated with the manufacture of turbine components, for example manual handling, use of machinery and equipment, electrical hazards and noise; however, most of the data and literature focus on the exposure to hazardous chemicals. The chemicals most routinely referred to are epoxy-based resins and glass-reinforced plastic (GRP) (Ponten et al. 2004; O'Neill, 2011; Rasmussen et al., 2005; Safety and Health Practitioner, 2009; Health and Safety Bulletin, 2009; Wood, 2009; Hammond and Blade, 2008; Hammond et al., 2011.

- Epoxy resins are synthetic chemicals traditionally used in paints, glue or composite materials and are now being used in the manufacture of wind turbine systems. There is a risk of contracting contact allergy and dermatitis when using these chemicals.
- Wind turbine blades are produced from GRP. The GRP manufacturing process has been established for a number of years, and although it is a relatively simple process, worker exposure to the solvent (styrene) vapour, which is released during the process, is notoriously difficult to control. The size of the article being manufactured can increase exposure to styrene. This is particularly pertinent for wind turbine blades as they can be up to 90 m long.
- Towers are made up of several steel segments placed on top of each other.

Two studies conducted within one manufacturing site (Ponten et al. 2004; Rasmussen et al., 2005) found that skin complaints were mainly associated with work in the finishing unit, which involves filling in any gaps on the blade edges, adding a thin coat of fibreglass to the leading edge and sanding down any imperfections and painting as required. Other clusters were found in the blade shell unit where moulds of blades are made and then filled with whichever material is being used, such as composites, and the unit where pre-impregnated carbon fibre materials are cut. An association was found between contact allergy to epoxy-based resin on diglycidyl ether of bisphenol A (DGEBA-R) and possible exogenous dermatitis (dermatitis caused by external factors), with an increase in cases found during the first year of employment.

Although susceptibility to dermatitis usually decreases with age, a cross-sectional study within a Danish company producing wind turbine systems found that older workers with a long employment history within the same organisation had an increased risk factor for allergy to workplace materials (Rasmussen et al., 2005). Control measures for dermatitis discussed within the literature include automating as much of the manufacturing process as possible and providing workers with information about the health risks associated with their work, as well as instruction, training and supervision (Ponten et al. 2004). However, the literature also highlights how the industry needs to continue to re-evaluate its health and safety systems as turbines get larger. In 2009, for example, workers were exposed to chemicals from splashes when they had to reach up to coat the blades of a 12-m wind blade, far higher than their risk assessments had allowed for. As a result, the sensitised workers had to be removed from further exposure. Although the company involved had health surveillance in place, the data did not feed into their management procedures (Wood, 2009).

A case was found where workers were exposed to epoxy resins through skin contact and it was reported that they experienced reproductive effects, including irregular periods. Women were warned not to have children for two years after exposure where poor or no protective measures were in place when manufacturing or repairing wind turbine blades with epoxy resins (O'Neill, 2011).

In another case, a company that focused solely on repairing defects in wind turbines by drilling, injecting specially devised sealant resins, sanding and then painting, found that some of its workers were reporting specific health concerns, including the stopping of menstrual cycles, severe headaches, nosebleeds and dizziness, as well as throat and eye irritation. The symptoms were attributed to the fact that the workers' tasks involved using endocrine disruptors and highly toxic carcinogens (Chulvi, 2008). The workers in this company wore gloves, overalls and safety glasses but reported that the chemicals would penetrate through the protective equipment if they made contact. As is often the case, personal protective equipment (PPE) in the form of gloves and masks is usually the only control measure in place, but it may not provide sufficient protection.

Exposure to chemicals in wind turbine manufacturing does not happen only through skin exposure. Inhalation of styrene vapours from the application and curing processes also presents a risk (Hammond and Blade, 2008; Hammond et al., 2011). In an attempt to reduce exposures to styrene vapour, NIOSH (Hammond and Blade, 2008) has been evaluating the use of vacuum-assisted resin transfer moulding (VARTM), which has the additional advantage of reducing dust and noise from the process. NIOSH found that the closed-moulding VARTM process is an effective way of controlling worker exposures to styrene, particularly during the gel coating of wind turbine blades. Other controls that are often considered include the use of a low styrene-content resin, non-atomising spray equipment and the use of appropriate PPE (Hammond and Blade, 2008). A utility-scale wind turbine blade manufacturing plant requested assistance from NIOSH in controlling worker exposures to styrene at a plant that produced 37- and 42-m-long fibre-reinforced wind turbine blades. The plant requested assistance from NIOSH because previous air sampling conducted by the company indicated concerns about peak styrene concentrations when workers entered the confined space inside the wind turbine blade. NIOSH researchers conducted two site visits and collected personal breathing zone and area air samples while workers performed the wind turbine blade manufacturing tasks of VARTM, gel coating, glue wiping and installing the safety platform. One of the issues that the study highlighted was the need to carry out design changes to the mould that would eliminate the need for workers to enter the wind blade during the glue wipe process. This was important because it dramatically reduced the exposure of workers to styrene. In addition, owing to the ototoxic effects of styrene, noise exposures also need to be taken into account in the workplace risk assessment and reduced. The use of hearing protection was, in that case, also recommended.

In addition to chemical hazards from exposure to epoxy resins, styrene and solvents, there are also other harmful gases, vapours and dusts created during the manufacture process to consider. Dust and fumes from fibreglass, hardeners, aerosols and carbon can cause common health-related problems including dermatitis, dizziness, drowsiness, sleepiness, liver and kidney damage, blisters, chemical burns and reproductive effects. As technology develops, workers are being designed out of the manufacturing process as much as possible through the use of robotic spray booths, but not all manufacturers have the resources to invest in updating their assets.

4.3 OSH risks associated with the transportation of wind turbine components and workers

The movement of enormous wind turbine components for hundreds of kilometres is a substantial logistics challenge for the wind energy sector. Moving a wind turbine that is 100 metres tall from the manufacturing site to the onshore site or the port, from where it will be transported to the offshore site, is no small feat and requires considerable planning. While transport to onshore wind farms is typically done by road, transport of wind farm components to offshore sites is done on marine vessels. The transport of large components is more challenging on roads than on marine vessels. Considering the remote location of most wind farms, both on land and offshore, the transportation of workers to these facilities also needs to be considered.

Transportation challenges will be specific to each wind farm, since each country or location will have different risks to contend with. For instance, in Finland, wind farms are mainly located in coastal areas where the required wind conditions exist and where there is access to harbours. However, in northern Finland access to these sites becomes difficult during the winter period.

In CWIF's database (CWIF, 2013), 115 transport-related accidents have been reported — including a 45-m-long turbine section ramming through a house while being transported, a transporter knocking a utility pole through a restaurant and a turbine section falling off in a tunnel. Most accidents involve turbine sections falling from transporters, though turbine sections have also been lost at sea, along with a 58 million euro barge. From the accidents reported in relation to wind energy work, transport is the single biggest cause of fatalities for workers, and this includes transport workers.

4.3.1 Transportation of components

Road transport

Most wind turbine components can be transported in sections, but they tend to be very large and in many cases are classed as an abnormal load for road-going vehicles. The Irish Wind Energy Association (IWEA, 2011) defines an abnormal load as ‘a vehicle or vehicle combination having either no load or an indivisible load, which can only be transported by exceeding at least one of the dimensions and/or axle, bogie or total weights authorised by Directive EC 96/53 (directive laying down for certain road vehicles circulating within the Community the maximum authorised dimensions in national and international traffic and the maximum authorised weights in international traffic) and national legislation’. In the wind energy sector it is wind turbine components and transformers that meet these criteria.

Normal road transportation risks are therefore increased by the specialised nature of the components in a wind farm:

- Rotor blades are relatively fragile, usually manufactured in sets to match a particular turbine, and can be longer than 50 m.
- Nacelles contain many relatively delicate parts such as the gearbox, generator, electric controllers and transformer.
- Nacelles can also be heavy, with limited lifting points and an offset centre of gravity.
- Tower sections are bulky and heavy.
- Step-up transformers are usually very large and heavy.

The hazards associated with the transport of wind turbine components include:

- People and load falls — an unsecured load that shifts is more difficult to unload. Sending someone up onto the trailer bed to handle a load that has shifted puts them at risk of falling.
- Vehicle rolls — vehicles can roll over; in serious cases of load shift, the vehicle can become unbalanced and overturn.
- Load shifts forward — if there is a gap between the load and the headboard, the load can shift forward under braking, risking the life of the driver and other road users.
- Collision with other vehicles — some of the remote locations used for wind farm sites will require the use of minor roads and track roads for the transportation of wind turbine components. Owing to the size and length of these vehicles there will be occasions when they have to cross the centre line of a road or even move along the wrong side of a roundabout, and this can put other road users at risk.
- Road restrictions — the dimensions of the transporters will create hazards associated with height and weight restrictions when travelling along bridges, tunnels, etc.
- Fatigue caused by driving excessive distances without an appropriate break. Sleep-related accidents are most likely to occur between 2 a.m. and 6 a.m. and between 2 p.m. and 4 p.m., which are times when abnormal loads are being transported.

According to IWEA (IWEA 2011), 50 % of transportation incidents on wind farms are caused by human-related behaviour, such as moving off the centre line of the road. If the vehicle becomes stuck, the driver may attempt to manoeuvre out of difficulty by moving off the centre line of the road without appropriate assistance, leading to a more serious incident. However, better planning should ensure that assistance is readily available, which can prevent the driver needing to move off the centre line of the road or getting stuck.

As early as possible in the design phase of the transportation project, key points such as those mentioned above need to be taken into consideration. This could include provision of escorts, contingency planning, identification and avoidance of restricted access routes, steep gradients, confined road corridors, road traction, limited turning points or forms of communication.

Figure 5: Lorry transporting material with safety outriders to allow safe manoeuvres

Source: Reproduced with permission of IWEA and Paul Whelan, © All Rights Reserved 2012.

One way of reducing the risks associated with transport accidents by better planning is to undertake a swept path analysis, which is a tool that can help anticipate and avoid dangerous situations when transporting turbine components. There could be several routes to a site and, through the use of computer simulations, it is possible to pinpoint the areas where additional information is required. By doing so, exposure to the dangerous parts of a road would be limited. In some cases it is even possible to have 'dry runs' (real trucks simulating the actual deliveries to site) that can help assess situations that could become dangerous for the drivers and other road users. These dry runs can confirm the suitability of an access route and will help to ensure that the actual delivery is undertaken in a safe manner.

As main roads are used to transport turbine components, the effect and impact of this transport on the safety and convenience of other road users also needs to be considered. To avoid interference with the main traffic flows, the majority of turbine traffic movement is done at night, although this is not always possible. An example of the transport of turbine components affecting the safety of other road users is when the transportation is done in convoys. This prevents other road users from seeing around all the vehicles and, with a safety distance of 60 metres between, it is impossible for a vehicle to overtake three trucks in a safe manner. In situations like this, the use of escort vehicles is necessary. The main functions of escort vehicles are to:

- provide an element of control on road users along particular sections of the route, e.g. when a load must cross the centre line of a road or move along the wrong side of a roundabout; and
- provide an element of warning and information for other road users about the proximity of the convoy.

Escort vehicles are also needed if road transport legal weights or minimum dimensions are exceeded.

Overall, there is a need for more risk awareness among transporters. They typically work long hours, at night and sometimes also in very poor weather conditions. This is seen as an increasing challenge for the industry to address.

For offshore wind farms, the transport of turbine components by road could be reduced. Indeed, as the size of wind turbines has increased, there has been a growing trend for manufacturers of wind turbine components to be sited at ports where most of the installation can be assembled before being transferred directly to specialist wind turbine installation sea vessels (Lawson, 2012). In Denmark, Germany and the United Kingdom there are ports that have been developed for this purpose. The advantage in terms of OSH is that it reduces workers' exposure to risk associated with road transport of components from manufacturing plants to the port as components no longer need to be transported to the port.

- **Offshore transport**

Compared with road transport, marine transportation can better accommodate very large, heavy turbine components — and components for offshore wind farms tend to be larger than for onshore wind farms. Transportation sometimes involves a fully constructed wind turbine.

The transportation of turbine components offshore poses additional risks to those already considered onshore, such as the following:

- During a voyage, a vessel is exposed to a number of potential hazards including heavy weather, stranding or collisions and fire.
- Vessels are subjected to six different motions at sea: rolling, pitching, yawing, surging, heaving and swaying. These motions, particularly rolling and pitching, can be magnified immensely during periods of heavy weather.
- Offshore wind farms are being constructed with bigger power ratings and at locations further from shore, therefore travelling distances are increasing.

With respect to the transportation of components from the port to the offshore site, RenewableUK has produced some guidelines for health and safety in the marine industry (RenewablesUK, 2012, 2013). Some of the OSH considerations include the selection of appropriate vessels, selection of suitable towing equipment, safe practices for line handling as laid out in the Merchant Shipping (Code of Safe Working Practices for Merchant Seamen) Regulations, 1998, Chapter 33 (Lawson, 2012) and the need to consider weather limits and forecasting. The limitation on the number of suitable installation vessels and cranes available for transportation (EWEA, 2011) is rapidly becoming a concern, particularly with the increase in number and size of offshore wind farms.

Logistical transfer: minimising risk

Safety Technology Ltd, a UK-based centre of wind turbine safety, has been investigating the growing safety and health risks involved in the logistical transfer of wind turbine components from quayside to construction. This process involves the handling and moving of very large, awkward loads, some of which can weigh up to 56 tonnes. The programme schedule has tight time constraints and can be easily deflected by changes in weather, shipping delays and availability, increasing the likelihood of accidents. The following stages were identified to help companies understand the risks and enable them to undertake specific tasks in order to prevent accidents from occurring:

Stage 1: Planning (a full review of relevant regulations applying to the complete transportation project must be carried out, as well as briefing meetings with all parties).

Stage 2: Minimising the risk (carrying out a full induction to port and site facilities with the provision of permits to work for all relevant personnel; site rules must be established and clear responsibility defined for the implementation of agreed rules to ensure that all personnel involved are introduced and briefed on these rules; loading and lifting plans must be scheduled and obtained prior to the beginning of work to ensure that the movement of all items is in accordance with UK legislation; and site familiarisation is essential to ensure that all personnel are introduced to incident-handling responsibilities and reporting procedures).

Stage 3: Supervision and control of activities (close liaison with dock management, flexibility in planning, good communication with local councils and carrying out on-site weekly 'toolbox talks', advice and additional training requirements, as well as the continual assessment of risks and safe systems of work).

As reported by the author, logistical coordination is essential to ensure safe and smoother transport and, at the same time, reduce expenditure from waiting time, especially evident at dockside.

Source: Dickins (2012), p. 53.

Helicopters can also be used for the transport of equipment to offshore locations. The usual approach is to winch down the equipment onto an installed platform; however, the weight of the equipment that can be transported is quite limited. However, in future it will be possible to use larger helicopters with more space and higher carrying capacity

4.3.2 Transportation of workers

The transportation of workers, particularly those working offshore, needs to be carefully considered.

No information related to the transportation of workers to onshore wind farms was found. This is, however, an operation that can be challenging because of the remote areas, often with poor communications in mountainous areas that are difficult to access, where many onshore wind farms are located. Appropriate vehicles properly maintained are therefore needed.

One of the main challenges when working on offshore wind farms is the transportation of workers and their access to the turbines through its entire life cycle. In an offshore environment, the transfer to the wind turbine is not a matter of a few steps on a normal staircase but an operation that may require the use of fall protection equipment, coordination between the technician and the vessel crew and additional climbing of ladders of 5 to 20 metres while exposed to the prevailing weather conditions. Offshore workers are normally transported by a vessel that has its own crew.

These workers are dependent on a complex logistical arrangement that includes transfer to and from a vessel or helicopter, coordination with other marine vessels, and extra marine rescue equipment (e.g. immersion suits).

The selection of vessels for transportation (EWEA, 2009) is important to ensure that workers complete their journey safely and that whole body vibration (WBV) and the resulting fatigue and discomfort is minimised so as not to impact on the worker's health and their capability to perform tasks safely. RenewableUK has produced a vessel safety guide, which provides guidance to offshore renewable energy developers. The guide considered effective vessel selection and operation and includes examples such as marine and project crew on small vessels being exposed to risk of injury arising from WBV or severe shock as a result of impacts, or the consequential risks associated with vibration that may cause fatigue or discomfort (e.g. sea sickness), which may impact on capability and safety (RenewableUK, 2012).

The following four different accesses can be used, taking into consideration that access is not always possible because of weather conditions:

- direct landing by use of vessel;
- boat landing with motion compensation;
- crane hoist; and
- helicopter.

According to a study funded by the We@Sea Consortium (Salzmann, 2004), the currently applied method to access offshore wind turbines is ship based (ship bow to ladder on wind turbine). The study highlighted that this method of access allows for safe transfers in only mild wave conditions, up to a significant wave height of approximately 1.5 m. However, the study concluded that, by using motion compensation, safe transfers could be made in seas with a significant wave height of over 2.5 m.

Helicopters provide another possible way to transport workers to offshore wind turbines, although this is considered too expensive to use routinely. This would require the addition of a fixed landing platform to either temporarily set down the helicopter or to lower personnel by winch. Currently, most nacelle designs do not allow a helicopter to land but some do enable personnel to be lowered onto it. As wind farms grow in size and locate further offshore, it is suggested that helicopter access will become more economically viable and helipads may then be provided, so that helicopters can land safely (EWEA, no date). As helicopter access is currently not widely used, there is very little literature on the subject.

In larger wind farms and those further offshore, sometimes a manned structure providing living quarters for turbine technicians, medical personnel and personnel watching the wind farm's remote monitoring systems is available. Such facilities that provide advanced rescue equipment and have a helicopter landing platform will eliminate the need to use vessels for transportation and will shorten travel time.

Table 5 provides some of the advantages and disadvantages of the various access methods currently being used in offshore facilities.

Table 5: **Advantages and disadvantages of the various offshore access methods**

Type of access	Advantages	Disadvantages
Direct landing	Simple	Sensitive to marine growth and icing
Boat landing with motion compensation	Not sensitive to marine growth	Installation of additional equipment on the vessel required

Type of access	Advantages	Disadvantages
Hoist by crane	Not sensitive to marine growth	Remote control of crane Maintenance offshore required
Helicopter	Not sensitive to waves Fast means of transport	Expensive

The evacuation of sick or injured persons would also need to be addressed when considering the transportation of workers. The following factors need to be taken into account:

- evacuating a sick or injured person from the nacelle may be challenging because of ladders inside and outside the wind turbine tower;
- evacuating persons from wind turbines as a result of changed weather conditions may also be a challenge;
- going further offshore implies that the farms could be beyond the range of rescue boats;
- generally, the use of helicopters close to an installation is risky; and
- the use of a vessel may be a better solution, but it is limited by sea conditions.

At an early stage, emergency and preparedness plans and training sessions should be established, so that workers know what they should be doing in case of an accident or emergency situation.

With an increasing number of offshore developments expected over the coming years, and with these becoming larger and further offshore, special attention needs to be given to how primary medical attendance would be provided. The difficulties of evacuation from offshore wind farms to onshore hospitals have been addressed in research carried out by an interdisciplinary team at the BG Trauma Hospital Hamburg (BG, 2010). The 'Rescue Chain Offshore Wind Research' focuses on the development of a rescue chain concept for trauma patients at offshore wind turbines and is based on a scientific understanding of rescue logistics, techniques and medicine. The ultimate aim is to make recommendations for the future development and implementation of a rescue chain and will address topics such as:

- analysis of existing rescue concepts for offshore wind farms;
- investigation and optimisation of existing restraint systems from a biomechanical–medical perspective;
- needs assessment of telemedical rescue assistance systems;
- analysis of previous accident scenarios in terms of necessary classification of trauma patient injuries, as well as acutely occurring and emergency diseases;
- analysis of existing safety and emergency training programmes;
- needs assessment of medical supplies and rescue measures, as well as additional PPE or communication facilities from a medical–scientific perspective;
- needs assessment of professional primary medical attendance;
- analysis of additional hazards for trauma patients and rescue staff considering the maritime environment and offshore weather conditions; and
- development of recommendations for optimum rescue concepts.

4.4 OSH risks associated with the construction of wind turbines

Construction is seen as the most complicated and possibly the most dangerous stage in a wind turbine's life cycle, as it involves the installation of major components, among them the foundation and transition piece and the assembly of the wind turbine. It includes most of the heavy lifting of turbine components together with the completion of multiple tasks in quick succession, and this presents a number of safety issues. Although the number of workers involved in the installation phase will depend on the size of the wind farm, this is the most personnel-intensive phase in its development and operation. Finally, it is important to remember that construction activities take place in windy areas and that turbine heights are designed to position the blades where the wind blows most strongly. The safety implications of working at height and the exposure to these high wind conditions need to be carefully considered throughout the construction phase.

Busy areas such as the North Sea will continue to see an increase in activities over the next few years. The offshore wind industry is competing for space with shipping lanes, offshore platform operators and other stakeholders. As oil and gas offshore platforms are generally accessed by helicopter, constructing offshore wind farms in the vicinity of these platforms is a challenging business. Consideration has to be given to helicopter safety issues and the amount of time during which a platform is inaccessible should not increase too much.

The key construction milestones for a wind farm consist of the following:

Onshore substation development

- Earthworks and screening mounds
- Construction of access roads
- Construction of control room
- Delivery of transformer
- Internal concrete roads and paving
- Electrical and mechanical installation
- Substation commissioning
- Installation of export cables
- Construction completed

Onshore wind farm

- Construction of access road
- Excavation of foundation
- Steel reinforcement and base
- Turbine base and transformer housing completed
- First tower section and nacelle installed
- Blade fitted
- Cable routing to substation

Offshore wind farm

- Offshore construction base built at port
- Foundation installation
- Offshore substations installed and array cable installation starts
- Installation of first export cable
- Turbine installation
- Installation of remaining export cables
- First power generated
- Final turbine installed
- Project handed over to operations and maintenance team

Table 6 gives some of the main hazards that workers will be faced with during the construction of wind farms both onshore and offshore.

Table 6: **Example of hazards encountered during the construction phase of wind farms**

Falling structures, loads or objects during lifting operations.
Falls from heights.
Mechanical hazards, such as contact with moving parts.
Offshore — marine operations and transportation, for example ship collisions or man overboard.
Electrical — short circuits, overcharge, electrostatic phenomena or falls due to shock.
Fire or explosion of turbine (use of combustible materials) or vessel.
Manual handling.
Ergonomics — physiological effects as a result of heavy lifting and repeated movements, fatigue from climbing ladders or working in confined spaces.
Working with dangerous substances.
Working in confined spaces — the configuration of all nacelles will classify them as confined spaces.
Environmental effects — wind, wave and currents, or lightning.
Organisational — time pressure, insufficient or lack of safety equipment, lack of competence or skills for wind energy sector, different actors/companies all involved in the same operation.
Exposure to noise and vibration.
Evacuation of persons from wind turbines as a result of changing weather conditions and locations may be challenging.

The development of onshore and offshore wind facilities requires extensive planning and thorough knowledge of site conditions, for example location, topography, ground conditions and other factors. Both on-land and at-sea operations will require a staging area for storing large components before the installation process begins.

Wind turbine construction requires some of the largest lifting equipment in use today and the lifting of components in excess of 80 tonnes to heights of over 90 m requires strict attention to safety. For example, a crane operator was killed while installing turbines at a site in Germany. The accident happened when a blade dropped onto the crane cabin during installation by the subcontractor (Lee, 2012). Owing to the size of the cranes used in both land-based and offshore projects, they need to be disassembled for transport and reassembled once they arrive at the project location.

Portable tower cranes set up near installations onshore pose risks such as overloading, unintentional movement of the boom or vehicle towards other workers, risks to workers in the tower cranes' blind zones, inadequate access to the cab and power line contact. Many crane incidents are due to inadequate bearing surfaces, so bearing pressures and ground surface capabilities should be determined with each activity, whether it is hoisting a load or walking the crane. During all major component lifts, crane mats should be placed on top of the crane pad. The Institute for Rural and Environmental Health at the University of Iowa, USA, made a number of recommendations for crane use (Public Health Department of Iowa, 2000), including the following:

- all outriggers should be on solid ground with no potential for shifting or settling;
- operators must regularly check and recheck the alignment of crane equipment according to the manufacturer's guidelines;
- additional means to anchor or secure tower cranes should be considered;
- employers are responsible for ensuring that all equipment is in good operating condition; and
- further safety engineering research should be undertaken to determine whether this type of crane is stable.

During land-based operations, cranes in the staging or warehouse area will load components onto trucks for transport to the installation site. Large cranes are also used to lift the individual components during assembly for both onshore and offshore wind facilities, although, as expected, the marine environment and the larger size of turbines introduces some additional hazards for the offshore construction workers.

In offshore projects, cranes load the components onto transport vessels, which are then floated to the project site. These cranes on vessels are available in different sizes depending on the weight of the components to be lifted and whether the load has to be lifted up to the working platform or the nacelle. The vessels used will depend on the lifting operation, but are normally floating vessels or jack-up barges. Offshore lifting operations need to consider the extreme weather conditions that will give rise to greater wind loads, the movement of the vessel during the lift, the limited working area available on the vessel, the motion of the turbine (in the case of floaters), the fact that the lift might be done over the vessel's deck and, finally, that there will be other vessels in the area involved in the construction process. For safer lifting operation at sea, jack-up barges equipped with several legs can be used. When the legs have been lowered to the seabed, the vessel can be jacked up above the water level, and is therefore independent of wave conditions. This allows the vessel to be in a completely stable position and allows precise lifting operations.

In 2010, GE Energy issued a press release to highlight the influence of wind forces during crane operation and to avoid accidents when performing lifts. It stated that 'lack of knowledge of the expected wind forces and the actual sail area of the load can lead to a failure of components and/or turning over of the crane'.

In 2011, the European Association of Abnormal Load Transport (ESTA) and the European Federation of Materials Handling (FEM) issued a warning about the risks associated with lifting operations and wind loads, for example cranes toppling onto workers and components hitting workers (Walsh, 2011). EN13000 should be applied correctly to calculate the continuous wave (Cw) measurement factor (wind loading in a particular situation), so that blades can be lifted in orientation to the wind. This will minimise the wind forces on the blades, so that the chance of them spinning during the lift is reduced. Crane operators are therefore reliant on blade manufacturers providing the correct information in the first instance, and ESTA and FEM have requested that blade manufacturers take greater care with their measurements and the information they provide, which could have a bearing on lifting operations.

Construction implications with 'far' offshore wind farm developments

Countries such as the United Kingdom and Norway have vast experience in the oil and gas offshore sector, and over the years have developed and implemented safety standards for these facilities. Many of these standards and best practices could be transferred to offshore wind farms; however, as newer wind farm developments are being built further offshore, to the extent that they are no longer visible from the coastline ('far' offshore), additional factors need to be taken into consideration, for example foundation design, logistics and OSH associated with the installation, operation and maintenance of the wind farm.

One such new development is the first German commercial offshore wind farm, BARD, which is located 100 km north-west of Borkum Island. By the end of 2013, 80 turbines with the potential to generate 400 MW will be installed — half of these have already been built and are connected to the grid. These turbines are being constructed in 40-m-deep waters and are as high as 80 m above the water surface. Approximately 500 workers were involved on the offshore construction and installation of the wind turbines. With the exception of the boat crew, most of these workers had never worked offshore. To ensure the safety of everyone involved in the project, a number of training centres were created onshore. The training provided included a two-day basic offshore safety training, which covered first aid, fire awareness, emergency rescue at sea, personal safety and helicopter underwater escape training. This training followed the GWO-certified training modules and, in addition, took into consideration standards from countries such as the United Kingdom, Denmark and Norway.

Workers and equipment were transported offshore by either helicopter or installation vessels. The transportation of the wind turbine components from the port to the offshore construction site located approximately 100 km away took 18 hours. The vessels used for transportation are equipped with 82-m-long steel ‘legs’, which allows them to be used as a construction site in waters up to 50 m deep. These vessels incorporate a crane that can lift and carry components of up to 500 tonnes — any lifting operation by the vessel offshore is conducted by only competent professionals.

Owing to the construction site’s distance from the coastline, the vessels are also used as accommodation platforms. The 18-person crew and up to 31 offshore workers can, at any one time, be accommodated within the vessel. Normally workers will spend 14 days offshore and then 14 days at home.

The monitoring of weather conditions at such a distance from the coastline is paramount, as the workers are exposed to stronger winds and wave actions. For example, lifting operations or the transfer from the platform to other vessels and between vessels becomes particularly difficult and unsafe. These variable conditions, which could change from day to day, determine whether the construction and installation work is carried out. This type of project highlights the importance of having an OSH team offshore.

In the case of BARD, after a difficult start, good cooperation developed between seamen and workers accustomed to onshore working. This, together with the training provided, resulted in considerable improvement in the conditions and, for example, low levels of staff turnover.

In Germany, OSH responsibility is region (Lander) based. However, areas further than 12 miles away from the shore are considered special cases (known as AWZs — exceptional commercial zones) as they do not belong to any specific region. To ensure the OSH of offshore workers, the federal administration for sea transport divided responsibilities for AWZs between the various coastal regions’ OSH administrations. They also developed a regulation together with the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA). Companies that wish to install and operate an offshore wind farm now have to demonstrate that they have a ‘prevention concept’, which is the basis for accident prevention and emergency planning for ‘far’ offshore installations.

Source: BG ETEM (2013)

Mobile cranes — the influence of wind forces during crane operation

During lifting operations wind forces may adversely affect loads and lead to a number of serious accidents, especially in the wind turbine industry. When lifting loads with relative small masses but large sail areas, the wind load has a considerable impact on the load carrying performance of the crane. The effective sail area of the load needs to take account of the projected area multiplied by the Cw factor (shape coefficient for the load). All parties responsible for planning the lifting operation must know the sail area and Cw factor. Additionally, it is mandatory for the crane operator to request information regarding the expected wind forces, including any gusts for the relevant environment from the responsible meteorological office prior to performing a lift and to take this information into account. The performance of a lift without knowledge of the expected wind forces and the actual sail area of the load can lead to a failure of components and/or turning over of the crane with potentially fatal consequences.

Source ESTA and FEM (2010)

Lowering the turbine into place is another potential area of risk, particularly when using large cranes where there is the potential for the wire rope to be compromised if it is not prepared correctly. In some circumstances double capstan winches could be a solution, but it is estimated that it will not be until 2018 that manufacturers will produce a double capstan. In the meantime, wind turbine generators will increase in size and weight, which will further complicate the operation and could increase the risk of accidents (Walsh, 2011).

One of the obvious hazards associated with working in wind farms both onshore and offshore is falls from heights, and this is to be considered during the construction phase, but it also applies to operation, maintenance and decommissioning stages. For example, a 19-year-old construction worker was killed after falling 30 m down the shaft of a wind turbine (BBC News, 2007). The wind turbine was under construction at the time and he was working inside the turbine. Throughout the construction of the tower, and then during the lowering of the turbine, workers are exposed to falls. They may be suspended in the air for hours at a time and may need to climb ladders and lift heavy materials. When working outside the turbine, certified anchor points and lanyards are needed for use during the installation of the turbine's nacelle and blades. Inside the tower, climbing the fixed ladders inside the wind turbine to the nacelle can take its toll on employees. These ladders require either a safety cage or a ladder safety device. Vertical fall arrest systems should span the entire height of the ladder and can include a stainless or galvanised steel cable or aluminium or stainless steel rail. The workers must wear full-body harnesses connected to vertical fall arrest systems by shuttles or sleeves that follow them up and down the ladder. In the event of a worker falling, a brake in the shuttle will engage to arrest the fall.

Accounting for one of the green job hazards in wind energy — falls

Workers who erect and maintain wind turbines can be exposed to fall hazards. Exposure to high winds may make work at high elevations even more hazardous. During installation, workers may need to access individual turbine sections to weld or fit individual sections together, run electrical or other lines, and install or test equipment — often at heights greater than 30.5 m. When exposed to fall distances of 1.8 m or more, construction workers on wind farms must be protected from falls by one of the following methods:

- guardrail systems;
- safety net systems; and
- personal fall arrest systems.

Source: (OSHA, no date)

Workers also have to carry with them all the tools and equipment they need, which may affect their balance and ability to arrest a fall, as well as cause fatigue and risk items being dropped from height. Harness systems should be carefully selected so that they are not only fit for purpose, lightweight and very durable to withstand harsh conditions, but also designed to incorporate tool-carrying accessories (Jervis, 2009). In order to avoid dehydration while working at height, crews also should consider hydration systems that clip onto harnesses. Dehydration can cause a number of ill health effects such as fatigue, fainting, increased blood pressure and, over the longer term, problems with the kidneys and urinary tract.

One solution for reducing the loss of or dropping of tools or instruments

The accidental dropping or misplacing of a hand-held instrument or tool, particularly when working aloft, is a potentially dangerous event that can be avoided. In addition to the hazard and lost downtime spent retrieving or searching for the dropped object, delicate instruments such as barcode readers and gas detectors can be damaged beyond repair. One solution is to use retractable gear attachment systems that offer the benefits of safety, productivity and comfort for workers. They prevent loss or damage of critical gear. If an instrument is dropped, the tether easily absorbs the stress produced by these heavier instruments. When the instrument or tool needs to be used, the worker simply needs to pull it out and use it and, when the work is finished, let it go, at which point it automatically retracts.

Source: (Dvorak, 2011)

The installation of electrical cables between turbines and the substation and the subsequent connection to the grid is done in a similar pattern for both onshore and offshore wind farms; however, the introduction of water in the offshore environment adds another dimension, because cable installation is accomplished by a diving operation or through the use of remotely controlled vehicles. Diving is a dangerous and physically demanding operation that can occur during various phases such as foundation installation, cable laying, welding and regular foundation inspections of and repairs to a variety of structures. Divers face numerous OSH hazards related to the diving itself and to working in an underwater environment with tools or machinery, including experiencing changes in pressure during descents to the seabed or ascents to the surface, wearing bulky and complex equipment and being submerged for potentially long periods of time. Divers must contend with specific site conditions, such as tides and other seabed hazards, and must work in low light or an artificial light environment. In addition, professional divers must often work with heavy tools or machinery. The work requires experienced and well-trained divers. All diving operations should be well planned and managed carefully throughout. Although remotely operated vehicles may be used in the future, especially for cable laying, professional divers continue to be used for many tasks in shallow water.

During the construction of offshore installations, because of the harsh environment, it is recommended that, wherever possible, diving operations and other work carried out offshore are kept to a minimum by carrying out as much work as possible onshore. In some cases all the pre-assembly is done offshore, whereas in others turbines are fully assembled onshore and then transported and set up on the substructure as one component.

The collapse of the tower and the rotor system could also occur during its installation. This type of failure would arise if the tower-fastening system is not installed properly, possibly because of improper torqueing of the base. In such cases, the tower will fall over as it is loosened and then becomes severed at the base of the flange. The collapse of the tower during the construction phase for both onshore and offshore facilities may have serious consequences in terms of injuries and fatalities.

4.5 OSH risks associated with the operation and maintenance of wind turbines

Once operational, wind farms are essentially unmanned facilities. Personnel access them only to perform maintenance and repairs. Unless they are involved in either planned or unplanned maintenance on a wind turbine, it is unusual for workers to be on site. During the construction phase, there could be more than 500 people working on site, but a typical operational crew will consist of two people for every 20 or 30 wind turbines in a wind farm. For smaller wind farms there may not be a dedicated operations and maintenance crew; instead, regular visits from regional teams are relied on.

Regardless of whether the wind turbine is onshore or offshore, once the technician is inside the turbine, the operational and maintenance tasks are exactly the same. Thus, the hazards and risks that these workers face are very similar. The main differences between onshore and offshore facilities are the means of transportation and the way in which the workers gain access to the turbine.

Currently, most of the operational data on turbines are kept confidential by the manufacturer, which may hinder the safe subcontracting of the operation and its efficient maintenance (IFC, 2007).

4.5.1 Operational issues

Once operational, there are a number of ways in which a wind turbine could fail and affect the OSH of personnel working in or around it. Table 67 gives some of the most common operational failure modes for wind turbines.

Table 7: **Operational failure modes for a wind turbine**

Failure mode	Means of failure
Tower collapse	Risk may arise from improper installation of the tower-fastening system, failure of one of its subsystems or catastrophic failure. The tower can also collapse as a result of buckling failure at some point midway up the tower if the overturning design loads in the tower base are exceeded. Compared with onshore structures, wave loading represents an additional source of dynamic excitation and fatigue for offshore facilities. Similarly, currents add an additional static loading. These dynamic amplifications, together with the highly corrosive environment, will have an influence on the turbine's foundations and the structural integrity of the tower.
Blade failure	Blades may be overstressed as a result of fatigue, wear and tear, excessive vibration and collapse from external loads. Blades have aeroelastic loads imposed from the wind and have experienced numerous problems as a result of structural demands. A study prepared by MMI Engineering Ltd for the Health and Safety Executive states that a full blade could reach a throwing distance of between 155 m and 198 m, while for a 10 % blade fragment the distance would be between 312 m and 1462 m, depending on the coefficient of drag (Health and Safety Executive, 2013). In 2010, a 140-turbine wind farm near Glasgow, UK, was temporarily shut down after a 14-tonne fibreglass blade broke off in windy conditions and landed at the base of its tower.
Tower strike	Tower strikes occur when a blade hits the support tower; these are relatively infrequent occurrences during the operation of modern wind turbine blades.
Fire	There have been a number of turbine fires, some caused by lightning, but many caused by a fault in the power pack or strong winds (e.g. a wind turbine caught fire when gusts of up to 250 km/h affected parts of Scotland).

Failure mode	Means of failure
	There have been cases of wind turbine housings catching fire. As the housings are normally beyond the range of standard fire extinguishing equipment and, in the case of older turbine units, lack fire suppression systems, it is almost impossible to extinguish such fires. In such cases, fire poses a hazard to workers who may be inside the nacelle and tower and people directly below the nacelle.
Lightning strike	Lightning strikes and thunderstorms can be frightening and dangerous for workers on a wind farm, particularly if they are working within the nacelle itself. A lightning strike may cause a fire, requiring the workers to either evacuate the structure quickly or be rescued. As an example, 14 % of all damages to turbines in Germany are caused by lightning.

Weather is another key operational feature that can create risks for workers on both onshore and offshore wind farms. Work plans should take into account information from national meteorological offices. The advice that national meteorological offices can provide to wind farm operators should not be underestimated. In Finland, because of its proximity to the Arctic Circle, weather conditions can make it particularly difficult for workers to carry out certain tasks, such as the operation and maintenance of wind turbines. To ensure that workers can take appropriate measures to prepare and protect themselves, the Harsh Weather Testing Network in Finland (Harsh Weather Testing Network, 2011) provides advance warning of adverse weather conditions, especially when ice formation is anticipated.

Ice throw/fall from the blades can be extremely dangerous, particularly for operators and maintenance staff, with fragments of ice up to 2 m long being thrown distances of over 100 m (Morgan et al., 1998; Harsh Weather Testing Network, 2012; Sieffert et al., 2003). To reduce the risk to workers from ice fragments, turbines should be shut down if ice is detected. Several methods of risk analysis can be used, but, according to a report published in 2003 (Sieffert et al., 2003), all these methods need to be improved and validated. Technology has advanced, so that rather than relying on meteorological predictions, sensors are used to detect build-up of ice on blades. The possibility of ice throw is a concern and building authorities in some parts of Germany and Austria require ice throw/fall prediction reports (Sieffert et al., 2003).

Although offshore wind farms share some of the risks with onshore installations, such as the risk of electrocution from the high voltage wires of the turbine when carrying out work in and around the wind installation, the offshore environment complicates safety. Once operational, offshore wind towers are normally unmanned, so they pose a limited risk to workers during the operational phase. The most dangerous element in the operation of an offshore wind farm is the transfer of personnel to the turbines for installation, inspection and maintenance. As the turbines can be accessed only by boat or helicopter, the ability to reach the turbines is highly dependent on the sea state. Workers may therefore find themselves stranded on a turbine structure if waves increase in magnitude while work is being conducted. The transmission platform might house personnel for indefinite periods of time, and this fact must be taken into account when designing for human safety in extreme conditions. The need for personnel to be stationed on a centralised transmission platform will increase as farms move further offshore and the logistics of personnel transfer to shore become more difficult. Designs must also address the potential need for stationing personnel on transmission platforms during inclement weather.

In addition to the above hazards, noise is an issue that is a recurring theme in the research considered (AWEA and CWEA, 2009; Australian Government NHMRC, 2010a; Australian Government NHMRC, 2010b; National Collaborating Centre for Environmental Health, 2010; British Wind Energy Association 2005; Raman, 2009; Keith, 2008; Heagle et al., 2011; Shepard et al., 2011), with the most recent, published in 2011 (Heagle et al., 2011), suggesting that there are few studies that actually look at the general health effects of small turbines and none that assesses the impact of noise on workers on wind farms. Noise in wind turbines is generated in two ways: mechanically, through the movement of parts near the generator, and aerodynamically, through the displacement of air caused by the turning of the blades. Generally, it is in the range of 35–50 decibel adjusted (dBA), which is comparable to indoor background noise. The perception of this noise differs among individuals, with some people defining it as an undesirable or unwanted sound (Australian Government NHMRC, 2010a). Wind turbine noise between 35 and 50 dBA can be associated with sleep interruption among people living less than 2.5 km from turbines, which may be an issue for offshore workers in accommodation platforms next to the turbine. Wind turbines may also generate low-frequency noise that is typically 50–70 decibel (dB). The health effects from long-term exposure to low levels of low-frequency noise are unknown (National Collaborating Centre for Environmental Health, 2010; British Wind Energy Association, 2005), but some claim that noise from wind turbines causes symptoms such as headaches, dizziness, unsteadiness, nausea, exhaustion, anxiety, irritability, depression, chronic sleep problems, anger, tinnitus and concentration and learning issues (Heagle et al., 2011). These symptoms are sometimes collectively referred to as wind turbine syndrome, but to date there is insufficient evidence to support the existence of this. In May 2010, the Chief Medical Officer of Health (CMOH) for Ontario in Canada published a report on the potential health impact of wind turbines (Chief Medical Officer of Health, 2010), which concluded that the scientific evidence available to date does not demonstrate a direct causal link between turbine noise and adverse health effects. While most of the research is based on the current wind turbine design of three blades, new designs now look at two blades or even one blade, which will be more cost-effective. However, having fewer blades would result in higher noise levels because of the higher speed of the blade tip. There is a need for more research on the impact of occupational noise on wind farm workers, in particular those working offshore and who need to stay next to the turbines in accommodation platforms.

Other potential health risks noted in a report by the CMOH in Ontario (Chief Medical Officer of Health, 2010) include shadow flicker, which occurs when the blades of the turbine rotate in sunny conditions and cast shadows. However, the CMOH discounts this as a potential risk given that only 3 % of people with epilepsy are photosensitive and that most turbines rotate at a speed below 5–30 Hz, which is the flicker frequency that usually triggers seizures. The CMOH also discounts the ill health effects of wind turbine-generated electromagnetic fields (EMFs), stating that wind turbines are not considered a significant source of EMFs (National Collaborating Centre for Environmental Health, 2010).

Because of the specific challenges associated with work on onshore and offshore wind farms, health surveillance of wind farm workers is very important.

Medical fitness to work — guidelines for near-offshore and land-based renewable energy projects

According to RenewableUK, it is important to medically assess both onshore and so-called ‘near offshore’ workers (i.e. where travel by boat or other means is less than two hours and involves no overnight stay offshore). A health assessment should be undertaken at pre-employment, pre-placement and after any significant incident, injury or sickness absence. Periodic assessments should be undertaken every two years but may be needed more frequently in individual cases when recommended by the examining physician. The assessment should consist of a medical history questionnaire, clinical examination and fitness assessment. The following list of medical conditions and symptoms is not exhaustive.

- Vision: Visual acuity must be adequate for safe work and will normally be at least a visual acuity of 6/9 in the better eye and 6/12 in the worse eye (with correction if worn).
- Hearing: Hearing should be assessed using a practical test.
- Cardiovascular system: Significant abnormalities of the cardiovascular system, including past myocardial infarction, cardiac surgery or percutaneous coronary intervention, will require medical assessment.

- Respiratory system: Climbing vertical ladders within turbine towers requires good respiratory function. Severe chronic obstructive airways disease, asthma or previous lung surgery may impact on fitness, so may require an assessment by the doctor.
- Musculoskeletal system: A full range of movement of the back, neck and all four limbs is necessary for safety when climbing vertical ladders and working in confined spaces within the nacelle.
- Nervous system: Any current or recent history of unexplained loss of consciousness, seizures, epilepsy or vertigo requires assessment.
- Diabetes: Well-controlled diabetic workers who do not suffer hypoglycaemic attacks may be considered fit, but should have a full medical assessment by the physician.
- Mental state: Mental illness involving psychosis or severe anxiety and depression is usually incompatible with work offshore as it may put workers' lives at risk.
- Drugs and alcohol: Workers' physical and mental fitness must not be impaired through the abuse of alcohol or prescribed or illicit substances, as these are likely to have adverse effects on their judgement, concentration, memory and behaviour and may put their lives at risk during wind farm work.
- Skin: Additional precautions are needed for sun-sensitive skin conditions when working outdoors.
- Peripheral circulation: Impairment of the peripheral circulation (e.g. Raynaud disease or the vascular component of hand–arm vibration syndrome) may be a contraindication because of the risks associated with work in cold conditions.
- Obesity: Obesity is not a contraindication per se, but agility and mobility must not be significantly impaired.
- Physical fitness to climb: Good cardiorespiratory physical fitness is necessary for the climbing aspect of work on wind turbine towers.

Overall guidance should be available on:

- Health assessment to detect and assess any medical conditions that may compromise safety by creating a risk of falling, sudden incapacity requiring rescue or an adverse impact on the safety of others.
- Fitness assessment to assure capability for regular climbing of vertical ladders and for working in hot, confined spaces.
- Climbing workload to provide a safe approach to managing work tasks by specifying climbing heights and frequencies.

Source: (RenewableUK, 2011a)

4.5.2 Maintenance issues

Once a tower is up and running, there are many maintenance procedures that must occur over the life of the structure. The typical routine maintenance time for a modern wind turbine is 40 hours a year (IFC, 2007). Maintenance issues have a link to design, particularly, as a typical installation may have a design life of 20 years, yet there are some parts of the installation, such as gear boxes, that may need to be repaired or replaced before then. Currently, gear boxes need to be replaced between 7 and 11 years into service (Puigcorbe and de-Beaumont, 2010). The more time a worker spends working on and maintaining a wind turbine, the greater the chance of his or her exposure to an OSH risk. In addition, owing to the shortage of skilled technicians in some EU countries, workers employed by some of the larger companies may be required to perform maintenance work in different countries, often working away from home for long periods.

Maintenance activities include common tasks such as cleaning blades, lubricating parts, full generator overhaul, replacing components and repairing electrical control units. These may be more repetitive tasks, which means that maintenance technicians become, in general, more familiar with the risks and the procedures in place for working at heights, interacting with electricity and working in confined spaces. Nonetheless, maintenance operations on wind turbines can be demanding and present a number of OSH hazards. The types of challenges faced by workers carrying out maintenance on onshore and offshore wind farms are various and linked as much to the challenges associated with the installation itself as to external conditions linked to the environment and weather conditions, which can be extremely difficult, especially at sea.

Wind tower components with the higher failure rates will require more maintenance interventions. Extreme weather conditions such as snow, strong wind and rain can all result in temperatures that range from the very low to the very high, and these harsh conditions, together with dirt, dust and lightning, also contribute to the blades having to be repaired or cleaned regularly. For example, despite the hard composite nature of wind turbine blades, the leading edges eventually show wear that changes their aerodynamic properties to the point where power production drops significantly and maintenance work is needed. The highest failure rates (Spinato, 2009), in descending order, are:

- electrical system;
- rotor (i.e. blades and hub);
- converter (i.e. electrical control, electronics, inverter);
- generator;
- hydraulics; and
- gear box.

Interestingly, the industry tends to focus on gear box failures, because these cause wind turbines to be non-operational for the longest period of time. There is little in th

e literature about the risk of electrocution from working on or maintaining electrical components. With regard to gear boxes, there has been some discussion about improving their reliability to reduce the instances of workers having to carry out maintenance, and newer turbine designs are opting for direct drive, which does away with gear boxes altogether (Puigcorbe and de-Beaumont, 2010; IFC, 2007, Professional Engineering, 2009). With regard to electrical risks, it appears that going over the nacelle may increase the risk of injury from sparking and electric shocks (which could lead to falls) or even electrocution, especially on some smaller, commercial-scale turbines that do not have brakes or shut-off mechanisms to prevent the turbine from accidentally being switched on during maintenance activities (see box, 'Good practice guide for wind turbines locking operations during service and maintenance activities').

Good practice guide for wind turbines locking operations during service and maintenance activities

To ensure the safety of workers involved in logging operations and maintenance of wind farms, it is necessary to identify, block, detach and free energy sources present in the wind turbines. Although the wind industry generally gives great importance to the prevention of risks, it must be recognised that there have been serious and fatal accidents caused by poor locking or disconnection of the equipment. To address this issue, a set of guidelines and criteria were developed to help companies and their workers identify, assess and control risks, and proactively manage and effectively prevent accidents involving all types of energy.

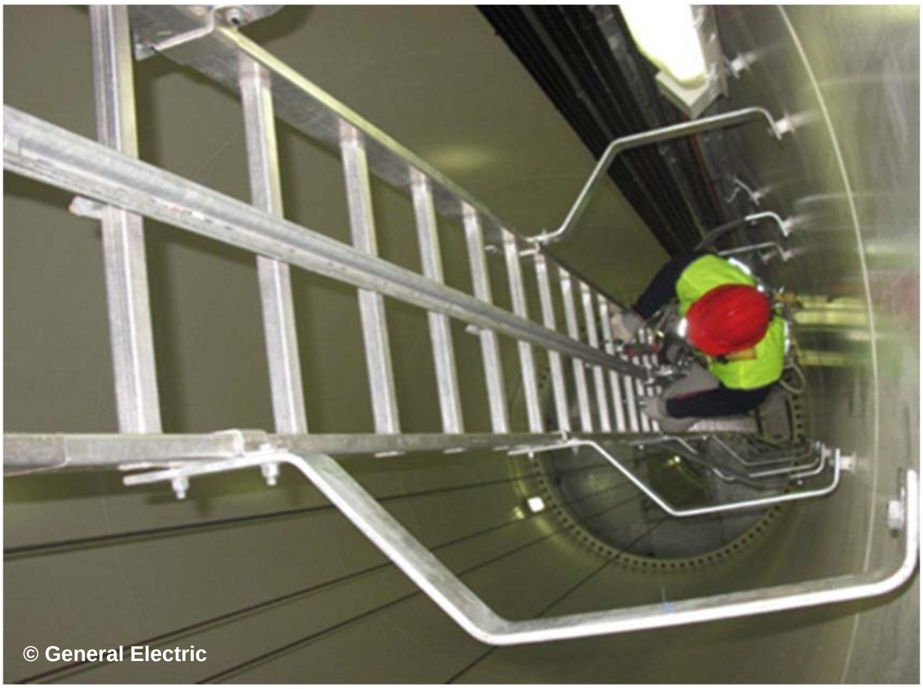
The good practice guide for wind turbine locking operations during service and maintenance activities includes relevant information concerning the control of dangerous energy sources. The main chapters are:

- legislation involving machinery directives and national laws;
- description and characterisation of wind turbine installations and electrical generator components;
- method to prepare a safe procedure to control hazardous energy;
- maintenance activities at wind turbines — different maintenance levels that are practised at wind turbines;
- training programmes;
- locking, labelling and marking equipment;
- standard documents and procedures during locking activities;
- locking case studies in the wind energy sector:
  - switching medium-tension cells (courtesy of MTOI — High-Tech in Wind Energy Generation)
  - locking the rotor (courtesy of MTOI — High-Tech in Wind Energy Generation).

Source: Cenifer (2012)

Maintenance work in, on or around the nacelle involves risks associated with moving parts should the nacelle turn, hot parts causing burns and high-voltage cables. If moving parts of the turbine (such as gears and blades) are not guarded properly they have the potential to cause severe injuries, such as crushed fingers or hands, amputations, burns or serious eye injuries that could lead to blindness.

Accessing the nacelle also means climbing very tall vertical ladders (e.g. 80 m high) when there is either no lift in the wind turbine or the lift has failed. Workers may have to climb several times during a shift. This generates a high physical load on workers and may result in musculoskeletal disorders and physical exhaustion. A certain degree of cardiorespiratory fitness and strength in the limbs is necessary.



Lift assist 'shortens' long ladders

As reported by a product manager for a safety equipment manufacturer, 'climbing 80 m to go to work may be routine for maintenance crews but three times in a day is a lot of climbing. Lugging up 10 kg or more of equipment makes a climb more demanding. What's worse, say maintenance people, is lugging it down' (Wind Power Engineering and Development, 2010). According to the manager, 'despite the relative good pay, many stay on the job only three to four years'. One solution to reduce staff turnover is to have a service lift or climb assist in place. Climb assists provide access for workers when towers are too small or are simply not designed to accommodate a service lift.

More recent designs are motor-driven continuous lines that loop from deck to deck. A worker will don a standard climbing, front D-ring harness, hook onto the lift line and signal the motor to start. This is done by pulling on the rope in the direction of the required motion, and then resisting the motor's pull to stop. When the motor does start, which can take a second or two, the lift is often too fast or too slow. The motor runs at its own speed and torque, so climbers accommodate motors and not the other way around. Some turbines have a straight run ladder from bottom to top, but an 80-m tower has about three sections about 25 m each. When climbing to the top, a technician may have to pass through multiple safety hatches at each deck. Going through a hatch requires a climber to stop, open the hatch, start through the hatch, stop to close the hatch door and continue climbing. The two- or three-second delay introduced a hassle factor.' This suggests that such climb assists may be more appropriate for small turbines, while lifts would better accommodate higher turbines.

Source: Wind Power Engineering and Development, 2010

To conduct inspections and maintenance tasks associated with the blades, workers can use similar fall protection systems and equipment to those used for wind turbine installation. In certain cases where workers need to access to the blades from the outside, more specialised access equipment and rope access techniques should be implemented. In the case of frequent maintenance operations, permanent systems such as horizontal rail systems attached to the nacelle, or ground-mounted lifts to carry technicians up to a platform, can also be installed to provide fall protection. Fall protection equipment for offshore workers is exposed to harsher elements, so it must be designed for extreme environmental conditions. It should offer a high level of moisture ingress protection, with its components completely sealed inside the housing to prevent saltwater corrosion. Fall arrest equipment and harnesses should also be washed in fresh water more often because excessive exposure to saltwater can damage equipment and put workers at risk (Global Wind Organisation, 2012).

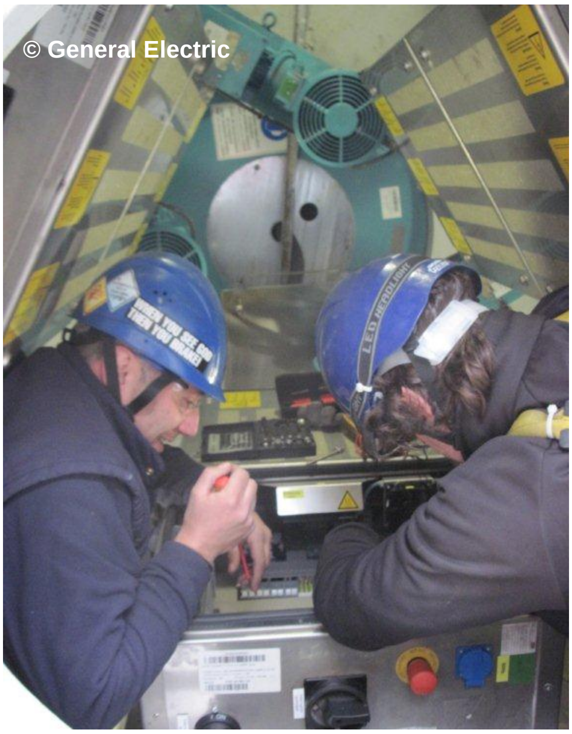
Maintaining turbine blades will also involve operations such as buffing and resurfacing, which may expose workers to harmful gases, vapours and dusts (Aubrey, 2011). When inside the turbine, adequate ventilation should be provided to reduce inhalation hazards. If the ventilation alone is not adequate, then workers may also need to use appropriate respirators. Use of respirators may give a false sense of security and workers should understand the limitations of the respirators. For example, during heavy exertion the respirator seal is often compromised, which allows the hazardous substance to enter the breathing zone (without being filtered) through the gaps between the respirator and the wearer's face. It is essential that workers are trained in the proper use of respirators, including storage and maintenance.

It is particularly important to monitor workers' exposure to gases and dust during work in confined spaces (Galman, 2009). Throughout the wind turbine there are a number of areas that can be defined as confined spaces, such as nacelles, blades, rotor hub, tower, tower basement and pad mount transformer vaults. Nacelles, blades, rotor hub, tower and tower basement have adequate size and configuration for worker entry but have limited means of access and egress and are not designed for continuous worker occupancy. The United Kingdom industry guidance recommends that specific considerations should be given to working in these confined spaces, for example:

- Oxygen depletion is always a concern when working in confined spaces. Toxic fumes can arise from heat or electrical sparks igniting solvent-based resins or other volatile organic compounds used to lubricate turbines, blades and electrical apparatus.

- Workers who must crawl into the narrow, culvert-like spaces of a blade to inspect the wind turbine lighting or to repair the blades or fibreglass skin can be subject to off-gassing from battery acids or volatile organic compounds.
- The decomposition of dead birds or rodents that may have found their way into the confined space may suck enough oxygen from the environment to cause unsafe oxygen levels.
- Exposure to biologically generated compounds such as moulds.

Any maintenance technician entering a confined space should carry a portable gas monitor in his or her toolkit and must test air samples before entering the confined space, as these will warn against multiple threats posed by confined space entry, for example detecting toxic gases in parts per million levels and flammable gases at the lower explosive limit. A standard four-gas detector will include sensors for monitoring oxygen, hydrogen, carbon monoxide and hydrogen sulphide. These four gases deserve special attention in confined space work. For a permit-required confined space entry, that is when the confined space has the potential for hazards related to atmospheric conditions (toxic, flammable, asphyxiating) engulfment or any other recognised serious hazard, a written permit to enter must be issued by the employer. This permit will provide details on the steps that need to be taken to make the space safe before and during the entry. Training on how to deal with these risks and hazards within the confined space and the use of the measuring equipment is paramount for all maintenance workers.



In addition to risks linked to hazardous substances and lack of oxygen in confined spaces, further issues such as ergonomics and musculoskeletal disorders linked to awkward, static postures need to be taken into consideration. Hot temperatures can also be an issue, for example when working within the nacelle, especially in summer, and this may also present a cardiovascular challenge. Maintenance workers must also be able to manhandle a colleague in a confined space should the colleague suffer a health problem. Assisting with the rescue of an ill or injured colleague, or even only having to be prepared to act in the case such a situation may occur, is a factor of work-related stress.

As with the construction and operational phases, emergency response planning and rescue plans need to be in place. Workers should receive appropriate training in rescue procedures, which will involve practice evacuations from the nacelle, which could detail the necessary action in any type of emergency, including in the event of a suspension trauma when a worker is in a harness, which equipment should be used and the different evacuation methods and procedures. These will depend on the type of wind turbine and whether it is onshore or offshore.

In offshore wind farms, diving operations present some unique issues for operators, not only during installation but also during maintenance (Atkinson, 2010). Within the United Kingdom, there are a number of guidelines including the Diving at Work Regulations 1997 and an approved code of practice (Health and Safety Executive, 1998). Steps to manage risk include designing out diving operations and using remotely operated vehicles where possible; ensuring the selection of a suitable vessel, safe method of access and egress from vessels; ensuring diver competency; and management of diving operations to include recompression and emergency response planning (RenewablesUK, 2010b, 2012).

Maintenance workers, particularly those working offshore, may be subject to time pressures owing to the availability of offshore weather windows, and this could militate against compliance with safe working practices (Health and Safety Executive, 2010).

In the United Kingdom, industry guidance recommends that planned preventative ([10]) maintenance should take place during the summer months, when weather conditions are better, and that such preventative maintenance contributes to avoiding the possibility of unplanned maintenance having to be carried out during the winter (RenewablesUK, 2010b). In contrast, a dynamic maintenance plan has been suggested, with work being carried out as and when required, rather than on a preventative basis, and non-urgent tasks being delayed to spring or autumn when weather conditions may be less extreme [96]. However, this type of plan is aimed more at improving reliability and costs than OSH. From an OSH perspective, climbs should be limited to wind conditions less than 40 mph (64 km/h), and work should be scheduled for good weather.

Scheduled maintenance is preferable to unplanned maintenance, which generally means poorer work organisation, and may involve workers who are not familiar with the wind farm/turbine to be maintained ad hoc and the specific challenges associated with its location. If reactive maintenance is required, it is recommended (RenewablesUK, 2010b) that consideration is given to weather working limits; the availability of sufficient light for operatives to work safely if night working is required; the availability of appropriate PPE depending on the tasks to be undertaken and location; and emergency procedures. Research is being carried out to further improve the online remote monitoring of equipment (Professional Engineering, 2009), which would reduce the need for unplanned maintenance.

To further reduce the need for maintenance and exposing workers to risk, it has been recommended that turbine subassemblies should be more thoroughly tested, particularly converters and generators, to eliminate early failures. Another suggestion is that nacelles should be tested at full or varying load, and at elevated temperatures to force early failures to occur, so that they enter service with an improved reliability (Spinato, 2009). This could apply equally to both onshore and offshore turbines. However, this does not take into account installations that go beyond their intended service life (Chartered Institute of Environmental Health, 2008).

4.6 Associated infrastructure

Both onshore and offshore installations require high-voltage intra-array cable networks to collect the generated power and transmit it to a substation; if the substation is offshore, then a transmission cable to the onshore grid will also be required.

These cables are heavy and awkward to handle, particularly subsea cables for use offshore. Of all the cables used, export cables tend to be the heaviest, with a diameter of around 200 mm and a weight of around 80 kg per metre length. These export cables can also be very easily damaged if they are not handled appropriately; if damaged, the subsequent repair work will increase offshore risk exposure (RenewableUK, 2013).

([10]) Planned preventative maintenance is where maintenance and inspections are scheduled at regular intervals to identify potential risks before they become problems.

Cable pulling operations involve high tensile forces being applied to cables to overcome the effects of their weight, and friction against surfaces that they are being pulled over. Pulling a cable into the wind energy generator transition piece typcally involves a tension of several tonnes; for example, pulling a cable across or under a beach would involve a much higher tension. In the event of any equipment breaking or becoming detached, the stored energy will suddenly be released, presenting a hazard to any people nearby. For offshore installations these operations are even more dangerous, as accurate tension control is more difficult to achieve when winches on floating vessels are pulling the cable into fixed structures, and also because of the restricted space available in the turbines.

Cable laying and routing will extend beyond the boundary of the wind farm development, therefore increasing the interaction with other land and sea users. This increases the risk to other people not just during the cable routing phase but also further on when other unrelated works are conducted in the vicinity of these high voltage cables.

The OSH risks to which workers can be exposed during cable laying onshore include working in pits and trenches, working in close proximity to other power lines or gas mains and other infrastructures, working in the vicinity of traffic, working in the confined space of cable tunnels and manual handling when handling cable drums when pulling cables. Care must also be taken when laying these cables, as they will subject induced voltages to other cables that run parallel or are in close proximity.

For offshore facilities, specialised handling facilities are required for the long lengths of subsea cables that are generally spooled into carousels on cable lay vessels. In order to ensure that the cable is properly layered in the carousel, this is assisted by people working within the carousel as the cable is wound inside; any loss of control of speed or tension would be very hazardous to the people working in such close proximity to the cable. This is further complicated if cables are transpooled between vessels (i.e. wound from the carousel on one vessel to another). The design of the carousel may also mean that these operations involve work at height.

Once laid, cables are generally protected by burial in the land or the sea bed; this is done either with a plough during cable laying or shortly afterwards by jetting a trench. In some locations, protection may be achieved by the use of concrete mattresses or rock placement. If protection is not applied immediately, then the cable is at risk of damage from activities such as vehicle movement onshore or trawling and anchoring offshore. Unless subsea cables are prohibited where cables are exposed, damage can also be caused by overstressing as a result of movement if cables are left unrestrained in locations with strong currents or wave motion. If a trawler fouls a cable and does not recognise the situation and take appropriate action in time, then this may result in capsizing. Effective cable burial therefore protects land and sea users, as well as the cable itself, but within certain limits; for example, extreme loads, such as those imposed by the leg of a jack-up vessel, can still damage cables that have been effectively protected against most other threats. Data from cable owners in the telecommunications industry indicate that around half of all subsea cable damage is from trawling, and around a third is from dragging anchors, as a result of either ships drifting off moorings or anchors inadvertently being released during storm conditions.

It is important that accurate information is made available for services maps, so that they show the precise location of cables onshore and offshore and also the location of land fall for subsea cables.

The intermittent nature of wind energy presents a challenge for the distribution network as well as for OSH, not only for workers working on the electricity substations that interface between the wind farms and the distribution network, but also for workers in other industries who may be affected by a power cut.

Overcapacity is required to prevent power cuts during spikes in demand, and secondary sources of power generation are required when the wind does not blow, for example energy storage in the form of batteries or super capacitors. It is beneficial to disperse wind farm locations over large areas, so that when wind is weak and power production is low in one area it can be subsidised by another. It has been suggested by the World Bank that these intermittency issues could be addressed by connecting all the countries of Europe to a single power grid and placing wind farms throughout the continent.

However, large weather systems can influence the European continent, including the British Isles, simultaneously and it has been demonstrated that even a ‘super grid’ with many wind turbines scattered over a large area could not cope with our modern-day energy requirements (van Kooten and Timilsina, 2009). Thus, another solution will need to be found to avoid power cuts and the subsequent OSH implications they would have.

Risk from electrocution and/or fire, particularly given wind turbines’ vulnerability to lightning strikes, is a real issue. To reduce the risk of electrocution or fire, all wind turbines and their associated hardware must be designed to be compatible with the relevant distribution network operator’s distribution code and must be compliant with any of their technical recommendations and safety rules.

4.7 Repowering/life extension

On land, expansion of wind energy is becoming increasingly difficult, as many of the most suitable sites are already taken and further extension of existing wind farms is restricted by the lack of wind in most of the inland regions and planning restrictions for interests (protection of the environment, nature conservation and landscape). With these constraints, repowering provides the possibility of increasing the production of electricity without simultaneously increasing the space required. Repowering can be defined as the replacement of older, smaller and less powerful wind turbines by newer, more powerful ones. Experience with wind turbines supports the idea that repowering can make economic sense well before the 20-year life expectancy is reached.

With regard to OSH implications, replacing major components during repowering of wind turbines will entail similar OSH risks as those discussed during the construction and maintenance phases. In addition, when planning the life extension/repowering of a wind turbine, it is important to plan an upgrade of its safety level and safety features at the same time (EU-OSHA, 2013).

4.8 Decommissioning

Wind turbines are expected to be operational for about 20 years. According to Vestas, the company which produced the first turbine in 1979, the operational lifetime of an active wind turbine can be 30 years or longer. So far, few turbines have been decommissioned (Martinez et al., 2010). In 2010, plans on how best to dismantle these multi-megawatt turbines at the end of their working life were still at the planning stage (Weinzettel, 2009).

The OSH risks associated with the end stages of a component or turbine's life are not well documented in the public domain, but it can be assumed that the same occupational risks will be associated with the decommissioning stage that may cause hazards in the construction and installation stage. It is clear that the dismantling processes for onshore and offshore wind farms are very different. The dismantling process and transportation process of an offshore wind farm are more complex and expensive than for its onshore counterparts because of climatic conditions (wind, waves, etc.) and its awkward location at sea (Ortegon et al., 2013). During the decommissioning stage, maritime weather conditions may have caused corrosion to the wind turbines, and this may pose a possible risk to the technical integrity of offshore wind farms. For example, one can envisage that during wind turbine decommissioning corrosion may cause failures and safety concerns (Tveiten et al., 2011; Albrechtsen, 2012).

In Denmark, where the industry is more mature, a group of key industry stakeholders formed a working party in 2012 to look at potential OSH issues associated with wind turbines as they reach their end-of-life stages. There are still first- and second-generation wind turbines in operation, which have been repowered. Technological advancements in the design and manufacture of wind turbine blades have extended the life of many wind turbines, but the earliest generations are less efficient and it is anticipated that in the coming years there will be an increased level of decommissioning activity and, with that, associated OSH risks.

4.9 Waste treatment and recycling

In the life cycle analysis for both onshore and offshore wind turbines, it is assumed that most of the materials of the wind turbine will be recycled at the end of their life cycle (Spinato, 2009; Cenifer, 2012; Chartered Institute for Environmental Health, 2008; Byon, 2010; Global Wind Organisation, 2012). In these assumptions, the tower and nacelle will be transported to a recycling plant and the blades will be sent to landfill.

The main materials used in manufacturing wind turbines are resin, fibreglass, iron, steel, copper and concrete. From these materials, iron, steel and copper are recyclable with only 5–10 % losses. Ferrous and non-ferrous metals can be used in a foundry after mechanical separation (Cherrington, 2012; Chartered Institute of Environmental Health, 2008). The recycling operations, for example mechanical separation and melting in a foundry, may pose the same hazards that have been encountered with other, similar, materials. It is essential that there are efficient control measures in these operations. For example, the workers may be exposed to inorganic and organic chemicals (e.g. metals) and dust in the foundries (Andersson et al., 2009; Siltanen et al., 1976; Tossavinen, 1976; Zakaria and El-Maghrabi, 2003; Lander et al., 1999; Weinzettel, 2009).

More specifically, regarding rotor blades, the future waste handling practices are still unknown. The main materials used in the manufacture of blades are reinforced fibres, such as glass fibres or carbon fibres bound by a plastic polymer-like epoxy resin. Polyurethane glue is the primary material used to assemble the blade shells and web (Spinato, 2009). There are three possible routes for disposing of dismantled blades: landfill, incineration or recycling. Wind turbine blades are mainly sent to landfill, but in several EU countries it is illegal to send composite materials to landfill (Martinez et al., 2010). Another common route is incineration. However, the ash that is left after incineration may be considered as a pollutant owing to the presence of inorganic materials in composites, and, furthermore, the flue gases may be hazardous. The last option is recycling as a material or as a product. However, at present there are few established methods for recycling of wind turbine blades. The blades will need to be cut into smaller parts to ease transport. There may also be some health and safety concerns in relation to toxic emissions, for example production of fine dust causing respiratory problems from the cutting and grinding of the blades (Global Wind Organisation, 2012; Galman, 2009; Ortegon et al., 2013; Larsen, 2009). Other materials, such as oil, other plastic and rubber, can be combusted or incorporated into fillers, insulation and cement (Galman, 2009).

5 Discussion — future challenges

Europe's ambitious programme to increase wind energy capacity so that it represents 25 % of EU electricity consumption by 2030 (EWEA, 2010) will require further efforts to consolidate and further improve OSH within the industry. Many of the OSH risks faced by the industry are not new as such, but are found in new, different situations or combinations that bring along new, different challenges.

5.1 Lack of OSH data and information

This review has attempted to bring together relevant OSH-related material in the wind energy industry by using data from national wind energy trade bodies and other stakeholders. However, it was evident that the amount of information available is rather sparse and in some cases extremely vague. This is mainly because of the following reasons:

- The existing fleet of wind turbines is relatively young.
- There is a lack of research/experimental data on risk exposures to workers — most research focuses on public safety.
- Businesses within the wind sector tend to be guarded not only at a recruitment and training level, but also at an operational level. The operational data of turbines are kept confidential by the manufacturer. Some wind energy operators share between themselves (mostly between members of wind energy trade associations) their data on OSH incidents and accidents but do not make this information public, thereby limiting possibilities for OSH actors to contribute to research and action to improve OSH conditions in the sector.

The debate on the adverse effects of wind turbines on human health and the environment has been on-going for many years. In 2012, the American Wind Energy Association, Australia's Clean Energy Council, the Canadian Wind Energy Association, the European Wind Energy Association, the Global Wind Energy Council and RenewableUK said: *'As a responsible industry that has been delivering clean electricity for more than 30 years, we collectively continue to engage with experts in science, medicine and occupational and environmental health to monitor on-going credible research in the area of wind turbines and human health…the balance of scientific evidence and human experience to date clearly concludes that wind turbines are not harmful to humans'* (Casey, 2013). This statement is based on the impact of wind energy on public health; it does not cover the OSH impact that the industry has on its own workers. CWIF has now included human health incidents in its accident database, including incidents associated with turbine noise, shadow flicker and so on. There were six incidents impacting on human health in 2012 and 11 up to 31 March in 2013. Such reports are predicted to increase significantly as more turbines are built. Considering the number of accidents and ill health incidents that have been reported and the hazardous activities to which wind energy workers are exposed, more occupational-based research is needed on new combinations of traditional risks in new environments, noise, vibration, electromagnetic radiation, use of dangerous substances, vibroacoustic disease and wind turbine syndrome.

Information on gender aspects of the workforce was not readily available. From articles such as 'Where are the women in wind?' (Rose, 2010), it is clear that, as mature and booming as the wind energy industry is in the EU, it remains overwhelmingly male dominated. Even though women working in the sector noted that it had been a good and nurturing fit for them, there are currently only a handful of women opting to work as wind turbine technicians. There is no evidence to suggest that women cannot cope with the physical and psychological demands of working on wind farms or that women with relevant qualifications might be excluded from, or self-exclude themselves from, fieldwork within the wind energy industry. However, during the manufacturing and repair of turbine blades there have been cases where women have been exposed to epoxy resins through skin contact. It was reported that they experienced reproductive effects including irregular periods and were warned not to have children for two years after the exposure. More OSH research is needed to identify other activities during the life cycle of the wind turbines that could have ill health effects for women at work and adequate prevention measures need to be implemented in order to protect both men and women from health hazards throughout the life cycle of wind turbines.

No literature was found on ageing workers in the wind energy sector. Some of the occupations within the wind energy sector are physically demanding, especially those that require climbing ladders in high wind towers or working in confined spaces for long periods of time, which may impact on health and may in turn affect the workability of older workers. As an example, technicians working in turbines frequently accelerate and stop their weight with each step on the way down, so the ergonomics involves more shock to the ankles and knees — despite the relative good pay, many stay on the job only three to four years (Dorvak, 2010).The wind energy sector is still relatively new, so it is important to conduct studies on the impact that these work activities could have on the long-term career and health not only of older workers, but of all workers who enter the industry.

The wind energy industry needs to understand the benefits of sharing OSH ideas and experiences (e.g. information on failures as well as successes) among themselves and with other industries, and how this would help to improve both OSH standards and working conditions for their workers. Keeping a sensible and constructive discussion going is important to achieving the most effective OSH regime. Safety is not a trade secret; openness should be promoted to strengthen safety work for all within the industry. Learning about and managing key risks by sharing incident reports and alerting others to potentially dangerous issues is key to preventing recurrences. It has also been suggested that, for the less mature offshore industry, it might be helpful to conduct further research on test/research of wind farms to identify the OSH issues and the level and type of risk assessment that is required.

5.2 Standards and guidelines

The lack of recognised standards and guidelines for the safe operation of wind farms, particularly for offshore facilities, has also been captured by the review. For a long time there have been no requirements in many countries for independent verification of the performance, durability and reliability of wind turbine products. It has been identified that, as technologies develop, standards have not always kept up with the pace of development and variations in product design. For example, at present standards are being developed for medium-sized wind turbines, which to date have used the same standards as those employed for large-scale wind turbines. However, this is either restrictive or not appropriate for the medium-scale wind market. It is also claimed that the available international standards for small wind turbines do not fully reflect the technical and economic demands associated with such turbines and their placement (IRENA, 2013).

Without clear guidance in place, national trade bodies have tried to improve standards within the industry by producing best-practice OSH recommendations; however, there is a clear need for the development of international standards or guidelines for OSH management that ensure a holistic approach from a life cycle perspective. Best practice and international standards provide a clear ability to provide products that are inherently safe and perform to set standards established by the international technical experts.

The European standard EN 50308:2004 'Wind turbines: Protective measures — Requirements of design, operation and maintenance' is currently being updated and it is expected that this standard will ensure that OSH is considered from the start of the turbines' life cycle.

5.3 Skills shortage and training

The rapid development of the wind energy sector over the past few years has resulted in severe skill shortages. TP Wind reports claims that this shortfall in skilled workers could climb to 28,000 by 2030 — nearly 5 % of the entire wind energy industry workforce. Wind energy cannot compete with traditionally higher salaries and opportunities offered by the oil and gas industry because the commercial returns are much smaller. This means that the majority of workers who are prepared to join the industry have little or no experience of working on wind farms and are not familiar with the OSH challenges they will face. It could be said that one of the attributing factors for this shortage in staff is the lack of an industry standard in practical wind energy training — training is an important part of preparing the wind industry to be reliable. There has been significant investment and work done to try and develop wind-specific training in Europe, for example inexperienced staff can now practise their techniques and new skills on dummy turbine masts. However, supplying training courses is being made more difficult and is, in a way, hindered by the inconsistent requirements of manufacturers and operators. With the formation of the GWO in 2009, a more integrated approach to OSH training across Europe is envisaged with the development of basic training that will include *first aid, manual handling, working at heights, fire awareness and offshore sea survival.*

In the TP Wind report 'Workers Wanted: The EU wind energy sector skills gap', health and safety is one of the top five areas where standardisation of training is suggested and may be beneficial (Fitch-Roy, 2013). Wind energy employers want to see more standardised programmes and the harmonisation of training certification (which would include the dissemination of appropriate educational content and techniques to industry) that would reduce costs and wasted time and also increase the mobility of the wind energy workforce.

5.4 OSH through the life cycle of a wind turbine

From the offset of the review, the collected data showed that wind energy workers both onshore and offshore will be exposed to OSH risks throughout the entire life cycle of a wind turbine. By using the life cycle model (design and development, manufacture, transport, construction, operation, associated infrastructure, repowering/life extension, decommissioning and recycling) to frame the review, it was possible to visualise the various complexities involved in any of the tasks or activities being undertaken on both onshore and offshore wind farms.

- **Design and development**

Design and development is a critical stage in minimising the potential for OSH issues throughout the life cycle of wind turbines. Discussion between designers and contractors can often result in a number of engineered solutions and more efficient operations that will minimise the amount of time workers spend on activities at all stages of the wind turbine's life cycle, for example employing remote diagnostics to reduce service and maintenance frequency. Minimising the need to visit turbines decreases the number of operational maintenance hours offshore, and therefore the overall risk to personnel. Some of the newer wind turbine concepts, such as floating platform technologies and airborne wind turbines or kits, can potentially reduce falls from height and musculoskeletal issues because they can simplify some of the more difficult tasks (EWEA, 2010; EERA, 2010; Byon, 2010). Some components on wind turbines have longer design lives, which, again, will improve the OSH of workers simply because they spend less time working in and around wind turbines on unscheduled maintenance tasks. Ultimately, there will be situations when a visit is unavoidable; the design should therefore allow technicians to safely and quickly deal with any issues. However, in an effort to make efficiencies, some potential OSH implications may have been overlooked. The use of nanomaterials in smart paint is a case in point. Smart paints were developed to help reduce weathering effects on wind turbine components. Owing to the conductivity of the paint it has also allowed for the use of remote control sensors and remote robots that can closely inspect the integrity of wind turbine blades from a remote control room. However, the use of nanomaterials raises potential issues for workers involved in manufacturing and at any other stage where repairs or decommissioning work might result in exposure to the paint or dusts containing carbon nanotubes or other nanomaterials. Although anecdotally there is some debate about the long latency of nanomaterials, there is some evidence that some types of carbon nanotubes may have asbestos-like effects. Another potential issue that is discussed within the industry but has not yet been tested to any significant extent is the change in turbine blade design that uses two or even one blade and produces higher noise levels as a result of higher speeds at the wind tip. As this illustrates, designers and developers need to consider fully the long-term impact of their designs and the materials they use on workers. Such is the fast pace of change in technology in the wind industry that health and safety risk assessments need to be dynamic and flexible enough to respond to these changes (Wood, 2009; United States Department of Labor, Occupational Safety & Health Administration).

Another concern that the report has raised is the suitability of the lifts that are currently being installed in many tall turbines. There is currently no European standard for turbine lifts and, although the benefits of providing lifts are acknowledged, it is suggested that the lifts currently being installed do not comply with the requirements of Directive 2009/104/EC (use of work equipment). Until recently, lifts have not been the default method of access technology used in the industry. However, in recent years the industry has taken a proactive lead in recognising that, with the growing size of turbines and the increasing number of turbines installed in the EU, there is developing evidence of the potentially wider operational and safety benefits of installing lifts. The need to manage working at heights has necessitated wind turbine operators to consciously consider the practicalities of lift installation. Without a specific turbine lift standard, the Working at Height and the Machinery Directive 2006/42/EC should be used together, as they set out specific duties concerning safe access relevant to the supply and installation of lifts. As lifts are becoming a more standard means of access technology, there is a need to increase the knowledge and understanding of the risks and benefits of installing lifts. This will require wind turbine designers to take a pragmatic case-by-case approach, reflecting current product development, to ensure the safest and most practicable means of access. At this design stage it is important to understand all risks, both direct and consequential, when planning safe access to turbines. Both the health and safety benefits and risks of installations should be considered; for example, installation could also lead to other risks and in particular electrical, fire and emergency rescue safety being compromised (RenewableUK, 2011b).

- **Manufacturing**

Manufacturing of wind turbines also presents some interesting issues for OSH. Exposures to chemicals, particularly epoxy-based resins, are not new hazards (O'Neill, 2007; Rasmussen et al., 2005; Safety and Health Practitioner, 2009; Health and Safety Bulletin, 2009; Wood, 2009), but as other materials are introduced into the manufacture stage the impact of technology on workers' OSH will need to be continually reviewed. The long latency of such chronic exposure should be fully considered during health surveillance and risk assessment. Newer manufacturing plants may invest more in up-to-date production processes such as robotic spraying booths that will reduce the exposure and immediate contact of workers to dangerous substances; however, the manufacturing processes will continue to have other OSH issues that need to be addressed. With wind turbines increasing in size, the impact of these larger and heavier components on the OSH of manufacturing workers needs to be assessed, especially with regard to the physical load on the body (manual handling, awkward postures, etc.). The trend for the manufacture of wind turbine components for offshore wind farms to be sited at key ports is an interesting development. Workers may potentially be fitting larger components together, so that they can be lifted directly onto specialist wind turbine installation vessels. There is further work that could be done to assess the musculoskeletal issues that may occur with the increased size of these components.

- **Transport**

The movement of enormous wind turbine components for hundreds of miles is more than a substantial logistics challenge for the wind energy sector. It also poses a number of OSH concerns for the workers involved. According to statistics reported up to 31 March 2013, there were 113 transport-related accidents reported — including a 45-m turbine section ramming through a house while being transported. Although most road accidents involve turbine sections falling from transporters, accidents can also involve vehicles rolling over, loads shifting forward and causing serious injuries to the driver and collisions with other vehicles, particularly on smaller off-roads. In the case of offshore transport, additional issues are introduced, such as the transportation of larger and heavier turbine components or even a fully constructed turbine, exposure to weather, stranding or collisions and being subjected to different motions such as rolling or pitching. To ensure the safe transportation of turbine components both onshore and offshore, the risks mentioned above need to be taken into consideration as early as possible in the design phase of the project. This would identify the type of provisions, such as the provision of escorts, contingency planning, restricted access routes, steep gradients, confined road corridors, road traction, limited turning points or forms of communication that will be needed. The changes towards the manufacture of components at ports will reduce some of the road transportation issues; however, as offshore wind turbines are being sited further away from the shore, the travelling distance required by workers on sea is increasing. It is not just the OSH implications of transporting components that requires consideration. Although immediate and obvious OSH concerns to workers can be identified and addressed, turbine-related work activities can also cause long latent conditions that appear only after a period of time has elapsed. One such condition is WBV, which is usually the result of travelling in unsuitable craft in rough seas.

Accessibility of offshore wind farms is highly dependent on weather windows and the technology chosen for the sea transport and transfer of construction, operation and maintenance personnel from vessels to the turbine. The overall strategy for the transfer of workers is sensitive to the access system selected and can be optimised by means of adequate predictive models in combination with effective technologies. Work continues to be conducted to make available access and transfer systems that focus on:

- rapid access to the wind farm on wider weather windows;
- transportation and transfers while avoiding sea sickness;
- provision of offshore accommodation; and
- allowing for fully motion-compensated transfers to the turbines.

The development of such systems will achieve higher safety standards and ensure the OSH of offshore wind energy workers.

Busy areas such as the North Sea will continue to see an increase in activities over the next few years. The offshore wind industry is competing for space with shipping lanes, offshore platform operators and other stakeholders. As oil and gas offshore platforms are generally accessed by helicopter, constructing offshore wind farms in the vicinity of these platforms is a challenging business. Consideration has to be given to helicopter safety issues and the amount of time for which a platform is inaccessible should not increase too much.

▪ Construction — control of contractors

Construction is seen as the most complicated and possibly the most dangerous stage of a wind turbine's life cycle, as it involves the installation of major components, among them the foundation and transition piece, and the assembly of the wind turbine. Although the number of workers involved in the installation phase will depend on the size of the wind farm, this is the most personnel-intensive phase in its development and operation.

During the construction period (which could take more or less than a year depending on the project size, location and weather conditions), construction workers, engineers, surveyors, turbine installers, electrical contractors, administrative employees and managers would all be working on site. In the BARD offshore project in Germany, for example, approximately 500 workers were involved on the offshore construction and installation of the wind turbines. This change in balance of contracted and inhouse work, together with an increased proportion of the work being on longer-term contracts, changes the emphasis of safety management effort.

As with any other construction work, the management of OSH in the supply chain is paramount. However, for the wind energy sector this is even more vital because most of these workers would have never worked in the wind energy industry, particularly offshore. The majority of works, for example design, construction, installation and commissioning, are generally undertaken by contractors. Successful management of the project will therefore depend on:

- the appointment of suitable competent persons for key safety-related roles;
- appropriate contractor selection, considering their safety culture and ensuring that the contractor's investment in developing competent people and safe methods brings a competitive advantage, rather than just a consideration of the initial cost;
- effective communication of safety information to the relevant personnel, including between contractors and phases of a project;
- agreement of suitable contractual arrangements, which promote safe working and define relevant key performance indicators; and
- effective monitoring of contractor performance according to key performance indicators and compliance with method statements.

(RenewableUK, 2013)

In previous offshore projects, in order to overcome a lack of experience or knowledge among contractors, a number of training centres were created onshore. The training included a two-day basic offshore safety training which covered first aid, fire awareness, emergency rescue at sea, personal safety and helicopter underwater escape training. These types of initiatives will ensure the safety of all personnel during the construction phase of the project.

- **Operation and maintenance**

Once operational, wind farms are essentially unmanned facilities with personnel accessing them only to perform maintenance and repairs. Regardless of whether the wind turbine is onshore or offshore, once the technician is inside the turbine, the operational and maintenance tasks that he or she will undertake are exactly the same. Owing to the pace at which the industry was developed, earlier first- and second-generation wind turbine designs that are still in operation did not have operational and maintenance OSH risks that we are now aware of designed out, for example workers having to make several climbs a day up the turbine or the need to work in confined spaces. Better engineering controls, reduced maintenance cycles and remote inspection on newer designs have improved the OSH of workers. Good management practices, including worker engagement, are key elements in promoting good OSH, but the industry should also be mindful that the pressure to work efficiently in what are often short periods of good weather has the potential to create stress on a workforce with high work demands. The development of offshore platforms in deep water and the requirement for workers to spend periods of time on accommodation platforms may require further investigations into the psychosocial issues associated with working on offshore wind farms.

- **Repowering and decommissioning**

Repowering has to some extent kept many wind farms beyond their intended life span, and there have been consequences for workers as the earlier generations of wind turbine design were smaller and accessed by ladders. Whilst some decommissioning activity has taken place, wind farms in areas such as Germany, Denmark, the United Kingdom and Spain, where the wind energy industry is more mature, will be faced with an increased number of decommissioning activities. The designs for these installations are unlikely to have considered their legacy, how they will be dismantled and the recycling of their parts. Inevitably these tasks will be undertaken by subcontractors, and duty holders will need to ensure that measures are put in place to oversee their activities and embed them into their OSH culture for the time they are on site. Duty holders will face challenges not just from subcontracted workers; the shortage of trained technicians could also mean that some companies become reliant on temporary agency staff, which makes it harder for managers to develop a culture of good OSH behaviours.

- **Waste management**

In the life cycle analysis for both onshore and offshore wind turbines, it is assumed that most of the materials of the wind turbine will be recycled at the end of their life cycle; however, turbine blades that are nearly all manufactured from thermoset plastic (the only material currently known that meets reliability standards owing to its relatively high strength and low weight) cannot be recycled once their useful life has expired. There are three possible routes for disposing of dismantled blades: landfill, incineration or recycling. Wind turbine blades are mainly sent to landfill, but in several EU countries it is illegal to send composite materials to landfill. Another common route is incineration. However, the ash that is left after incineration may be considered as a pollutant because of the presence of inorganic materials in composites; furthermore, the flue gases may be hazardous. The last option is recycling as a material or as a product. However, at present there are few established methods for recycling of wind turbine blades. The blades would need to be cut into smaller parts for ease of transport, and this can result in respiratory problems caused by the fine dust produced during the cutting and grinding of the blades. This lack of forward planning means that the future of waste handling for rotor blades and their OSH implications are still unknown.

6 References

Albrechtsen, E., 'Occupational safety management in the offshore wind industry — status and challenges', *Energy Procedia*, Vol. 24, 2012, pp. 313–321.

Alstom, *Haliade™ 150–6MW offshore wind turbine*, 2012. Available at: http://www.alstom.com/Global/Power/Resources/Documents/Brochures/offshore-wind-turbine-6mw-robust-simple-efficient.pdf

American Wind Energy Association and Canadian Wind Energy Association, *Wind turbine sound and health effects. An expert panel review*, 2009. Available at: http://awea.rd.net/Resources/Content.aspx?ItemNumber=4627 (accessed 15 November 2013).

Andersson, L., Bryngelsson, I. L., Ohlson, C. G., Naystrom, P., Lilja, B. G. and Westberg, H., 'Quartz and dust exposure in Swedish iron foundries', *Journal of Occupational Environment Hygiene*, Vol. 6, No 1, 2009, pp. 9–18.

Asociación Empresarial Eólica (EAA), 'Informe de índices de siniestralidad del sector eólico', informe no.3, Periodo 2007-2013, 12 April 2013. Available at: http://www.aeeolica.org/uploads/documents/5324-informe-de-indices-de-siniestralidad-del-sector-eolico-informe-3-periodo-2007-2012.pdf (accessed 15 November 2013).

Atkinson, P., 'Securing the safety of the offshore wind workers', *Renewable Energy Focus*, May/June 2010, pp. 34–36.

Aubrey, C., *Blade maintenance: keeping the elements at bay.* Wind directions, 2011. Available at: http://www.ewea.org/fileadmin/emags/winddirections/2011-12/pdf/WD_Dec%202011_FINAL.pdf, pp. 48 – 49 (accessed 15 November 2013).

Australian Government, National Health and Medical Research Council, *Wind turbines and health: a rapid review of the evidence*, 2010a. Available at: http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/new0048_evidence_review_wind_turbines_and_health.pdf

Australian Government, National Health and Medical Research Council, 'Wind turbines and health. NHMRC public statement', 2010b. Available at: http://www.nhmrc.gov.au/guidelines/publications/new0048 (accessed 10 April 2012).

BBC News, 'Man dies after 100ft turbine fall', 2007. Available at: http://news.bbc.co.uk/1/hi/scotland/tayside_and_central/6685447.stm

BG, Berufsgenossenchaftliches Unfallkerankenhaus Hamburg, Rescue Chain Offshore Wind, 2010. Available at: http://www.buk-hamburg.de/files/rettungskette_offshore_englisch_web.pdf (accessed 15 November 2013).

BG ETEM Energie Textil Elektro Medienerzeugnisse, *Magazin für Prävention, Rehabilitation und Entschädigung*, 4 August 2013.

British Wind Energy Association, 'Low frequency noise and wind turbines', *BWEA briefing sheet,* 2005. Available at: http://www.dpea.scotland.gov.uk/Documents/qJ12843/A2382521.pdf (accessed 15 November 2013).

Bundesverband WindEnergie, 'GWEC: wind energy powers ahead despite economic turmoil', 2012. Available at: http://www.wind-energie.de/en/infocenter/articles/gwec-wind-energy-powers-ahead-despite-economic-turmoi (accessed 22 May 2012).

Byon, Y. D, 'Season-dependent condition based maintenance for a wind turbine using a partially observed markove decision process', *IEEE Transactions on Power Systems,* Vol. 25, No 4, 2010, pp. 1823–1834.

Casey, Z., 'No link between wind turbine and adverse health effects', 2013, EWEA blog. Available at: http://www.ewea.org/blog/2013/05/no-link-between-wind-turbines-and-adverse-health-effects/

Cenifer, *Guía de buenas prácticas para la consignación de aerogeneradores en las operaciones de explotación y mantenimiento*, 2012 Available at: http://www.aeeolica.org/uploads/documents/2866-guia-para-la-consignacion.pdf

Chartered Institute of Environmental Health, 'Wind turbine maker launches safety inquiry', 26 September 2008.

Cherrington, R., Goodship, V., Meredith, J., Wood, B., Coles, S., Vuillaume, A., Feito-Boirac, A. Spee, F. and Kirwan, K., 'Producer responsibility: Defining the incentive for recycling composite wind turbine blades in Europe', *Energy Policy*, Vol. 47, 2012, pp. 13–21.

Chief Medical Officer of Health (CMOH), *The potential health impact of wind turbines*, CMOH, Ontario, Canada, May 2010.

Chulvi, B., 'Trabajadores desprotegidas ante el riesgo químico. Y por casualidad… …se descubrió el pastel', Fundación para la Prevención de Riesgos Laborales, 2008. Available at: http://www.porexperiencia.com/articulo.asp?num=40&pag=18&titulo=Trabajadoras-desprotegidas-ante-el-riesgo-quimico-Y-por-casualidad...se-descubrio-el-pastel (accessed 21 August 2012).

Clarke, P., *Health & safety on wind farms — the PowerGen approach*, PowerGen, pp. 25–31.

Cook, N., 'The wind of change', *The RoSPA Occupational Safety and Health Journal*, January 2011, pp. 25–29.

CWIF (Caithness Windfarm Information Forum), 'Summary of wind turbine accident data to 30th September 2013', 2013. Available at: http://www.caithnesswindfarms.co.uk/accidents.pdf (accessed 15 November 2013).

D'Souza, N., Gbegbaje-Das, E. and Shonfield, P., *Life cycle assessment of electricity production from a Vestas V112 turbine wind plant*, Vestas Wind Systems A/S, Randers, Denmark 2011.

Danish Energy Agency, *Wind turbines in Denmark,* 2009. Available at: http://www.ens.dk/sites/ens.dk/files/supply/renewable-energy/wind power/Vindturbines%20in%20DK%20eng.pdf (accessed 15 November 2013).

Danish Energy Agency, 'Wind power', 2012. Available at:

http://www.ens.dk/en/supply/renewable-energy/wind-power/offshore-wind-power

http://www.ens.dk/en/supply/renewable-energy/wind-power/facts-about-wind-power/key-figures-statistics (accessed 18 June 2012).

Deign, J., (2011) "Monopile failures put grout in doubt," Wind Energy Update. Available at: http://social.windenergyupdate.com/offshore/monopile-failures-put-grout-doubt

Department of Health and Human Sciences (National Institute for Occupational Safety and Health), *Summary of the Making Green Jobs Safe workshop*, 14–16 December 2009, Mandarin Hotel, Washington, DC., 2011, publication number 2011-201, NIOSH. Available at: http://www.cdc.gov/niosh/docs/2011-201/pdfs/2011-201.pdf

Dickens, R., 'Logistical transfer: minimising risks', *Real Power*, issue 27, January–March 2012, p. 53. Available at: http://www.renewableuk.com/en/publications/index.cfm/real-power-issue-27 (accessed 15 November 2013).

Donaldson, K., Murphy, F. A., Duffin, R. and Poland, C. A., 'Asbestos, carbon nanotubes and the pleural mesothelium: a review and the hypothesis regarding the role of long fibre retention in the parietal pleura, inflammation and mesothelioma', *Particle & Fibre Toxicology*, Vol. 7, 2010, p. 5.

Duff, J. 'Training wind energy workers', *Occupational Health & Safety,* 1 April 2010, p. 4447.

Dvorak, P. (2010). 'Lift assist "shortens" long ladders', 2010. Available at: http://www.windpowerengineering.com/maintenance/safety/lift-assist-%E2%80%98shortens%E2%80%99-long-ladders/ (accessed 21 August 2012).

Europa, 'Promotion of offshore wind energy', 2009. Available at: http://europa.eu/legislation_summaries/energy/renewable_energy/en0001_en.htm (accessed 2 May 2012).

EU-OSHA (European Agency for Safety and Health at Work), *Green jobs and occupational safety and health: Foresight on new and emerging risks associated with new technologies by 2020*, 2013. Available at: https://osha.europa.eu/en/publications/reports/green-jobs-foresight-new-emerging-risks-technologies/view

European Association of Heavy Haulage Transport and Mobile Cranes Group and European Federation of Materials Handling, 'Mobile cranes — influence of wind forces during crane operation', 2010. Available at: http://www.fem-eur.eu/data/File/FEM%20PG%20CLE%20ESTA%20Press%20Release%20Wind%20Influence.pdf

European Commission, 'Snapshot on European wind energy', Joint Research Centre, 2011a. Available at: http://ec.europa.eu/energy/publications/doc/2011_renewable_energy_snapshots.pdf

European Commission, '2011 Technology Map of the European Strategic Energy Technology Plan (SET-Plan)', *JRC scientific and technical reports,* European Commission, Joint Research Centre, Institute for Energy and Transport, 2011b. Available at: http://setis.ec.europa.eu/about-setis/technology-map/2011_Technology_Map1.pdf/view (access 15 November 2013).

European Commission, 'Wind energy generation, Strategic Energy Technologies Information System', 2012. Available at: http://setis.ec.europa.eu/technologies/wind-energy (accessed 15 November 2013).

European Energy Research Alliance, 'The EERA joint programme on wind energy', 2010, Available at: http://www.eera-set.eu/set.eu/index.php?index=23 (accessed 18 June 2012).

European Environment Agency, 'Europe's onshore and offshore wind energy potential. An assessment of environmental and economic constraints', EEA Technical report No 6/2009, 2009. Available at: http://www.mng.org.uk/gh/resources/Europes_onshore_and_offshore_wind_energy_potential.pdf

EWEA (European Wind Energy Association), *Offshore report, Oceans of opportunities,* 2009. Available at http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Offshore_Report_2009.pdf (accessed 15 November 2013).

EWEA (European Wind Energy Association), *European Wind Energy Platform, wind energy technology roadmap implementation plan 2010—2012*. 2010. Available at: http://ec.europa.eu/energy/technology/initiatives/doc/wind_implementation_plan_final.pdf

EWEA (European Wind Energy Association), *Wind in our Sails: The coming of Europe's offshore wind energy industry,* EWEA, Brussels, 2011.

EWEA (European Wind Energy Association), Wind in power 2012a European statistics February 2013. Available at http://www.ewea.org/fileadmin/files/library/publications/statistics/Wind_in_power_annual_statistics_2012.pdf (accessed 15 November 2013).

EWEA (European Wind Energy Association), *Wind energy factsheets*, 2012b. Available at: http://www.ewea.org/wind-energy-basics/factsheets/ (accessed 14 November 2012).

EWEA (European Wind Energy Association), Green Growth the impact of wind energy on jobs and the economy, April 2012c. Available at http://www.ewea.org/uploads/tx_err/Green_Growth.pdf (accessed 15 November 2013).

EWEA (European Wind Energy Association), 'Wind energy FAQs', 2013. Available at: http://www.ewea.org/wind-energy-basics/faq/

EWEA (European Wind Energy Association) European Wind Energy Platform, 'Wind turbine technology for offshore locations', no date. Available at: http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-turbine-technology-for-offshore-locations/ (accessed 14 November 2012).

Eurostat, 'Energy: Renewable energy primary production: biomass, hydro, geothermal, wind and solar energy', European Commission, 2012. Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables (accessed 26 September 2012).

Fitch-Roy, O., 'Workers wanted: The EU wind energy sector skills gap', 2013. European Wind Energy Technology Platform. Available at: http://www.ewea.org/fileadmin/files/library/publications/reports/Workers_Wanted_TPwind.pdf

Galman, D., 'Cultivating safety at wind farms,' *Occupational Health & Safety Journal,* January 2009, p. 28.

Global Wind Energy Council, 'Global wind report — annual market update 2011', 2012, Available at: http://gwec.net/wp-content/uploads/2012/06/Annual_report_2011_lowres.pdf

Global Wind Energy Council, 'Wind in numbers', 2013. Available at: http://www.gwec.net/global-figures/wind-in-numbers

GWO (Global Wind Organisation), *Basic safety training (onshore/offshore), version 0-2-02-2012*.

Hammond, D. and Blade, L. M. 'Walk-through survey report: styrene exposures during fiber reinforced wind blade manufacturing', US Department of Health and Human Services, Report No. EPHB 306-19a, Washington, DC, 2008.

Hammond, D., Garcia, A., and Feng, H. A., 'Occupational exposures to styrene vapor in a manufacturing plant for fiber-reinforced composite wind turbine blades', *Annals of Occupational Hygiene,* Vol. 55, No 6, 2011, pp. 591–600.

Harsh Weather Testing Network (2011). Harsh Weather Testing Network. Retrieved 21 August 2013, from: http://www.harshnet.eu

Heagle, A. L. B., Naterer, G. F. and Pope, K. 'Small wind turbine energy policies for residential and small business usage in Ontario, Canada', *Energy Policy*, Vol. 39, 2011.

Health and Safety Bulletin 'Dermatitis costs wind-turbine manufacturer £35,000,' August/September 2009, p. 381.

Health and Safety Executive, *Commercial diving projects inland/inshore. Diving at Work Regulations 1997. Approved Code of Practice* L104, HSE Books, 1998.

Health and Safety Executive, 'Health and Safety in the new energy economy'. 2010. Available at: http://www.hse.gov.uk/eet/assets/pdf/new-energy-economy.pdf.

Health and Safety Executive, 'Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines', 2013. Available at: http://www.hse.gov.uk/research/rrpdf/rr968.pdf

Heenan, J., 'Health and safety trends in the wind industry', 2012. Available at: http://www.aeeolica.org/uploads/documents/ieiprse2010/03-James%20Heenan_GEWE.pdf. (accessed 15 August 2012).

International Electrotechnical Commission, 'IEC 61508', 2012. Available at: http://www.iec.ch/functionalsafety/faq-ed1/page4.htm (accessed 15 August 2012).

International Finance Corporation, *Environmental, health and safety guidelines for wind energy,* 2007. Available at: http://www.ifc.org/wps/wcm/connect/3af2a20048855acf8724d76a6515bb18/Final%2B-%2BWind%2BEnergy.pdf?MOD=AJPERES&id=1323162509197

IRENA, 'International standardisation in the field of renewable energy', 2013. Available at: http://www.irena.org/DocumentDownloads/Publications/International_Standardisation_%20in_the_Field_of_Renewable_Energy.pdf (accessed 15 November 2013).

IWEA (Irish Wind Energy Association), *Transport of abnormal loads to windfarms*. Draft Consultation on Safety Excellence Standards, May 2011. Revision 1.3.

Jervis, S., ' Fall protection considerations in the wind energy industry', *Occupational Health and Safety Journal*, January 2009, pp. 26–32.

Keith, S. E. 'Community/industry interaction', *Journal of Low Frequency Noise Vibration & Active Control*, Vol. 27, No 4, 2008, pp. 253–265.

Kensche, C. W., 'Fatigue of composites for wind turbines', *International Journal of Fatigue, Volume 28* 2006, pp. 1363–1374.

Knowledge Centre WMC (Wind turbine Materials and Constructions), 'Optidat database', 2012. Available at: http://www.wmc.eu/optimatblades_optidat.php (accessed 9 May 2012).

Lander, F., Kristiansen, J. and Lauritsen, J. M., 'Manganese exposure in foundry furnacemen and scrap recycling workers', *International Archives of Occupational and Environmental Health*, Vol. 72, No 8, 1999, pp. 546–550.

Larsen, K., 'Recycling wind', *Reinforced Plastics*, Vol. 53, 2009.

Lawson, J. 'Offshore wind turbines transporters rise to the challenge', 2012. Available at: http://www.renewableenergyworld.com/rea/news/article/2012/02/offshore-wind-turbines-transporters-rise-to-the-challenge (accessed 14 November 2012).

Lee, A. (2012). 'Falling blade kills worker during Vestas installation in Germany', Recharge News. Available at: http://www.rechargenews.com/wind/article1301409.ece

Martinez, E., Jimenez, E., Blanco, J. & Sanz, F., 'LCA sensitivity analysis of a multi-megawatt wind turbine', *Applied Energy*, 2010, Vol. 87, No 7, pp. 2293–2303.

Morgan, C., Bossanyi, E. and Seifert, H., 'Assessment of safety risks arising from wind turbine icing', *Proceedings of BOREAS IV*, 31 March to 2 April 1998, Hetta, Finland, 1998.

National Collaborating Centre for Environmental Health, 'Wind turbines and health — evidence review', 2010. Available at: http://www.ncceh.ca/sites/default/files/Wind_Turbines_January_2010.pdf

Nicola, S., 'Germany's $263 billion renewables shift biggest since war', *Bloomberg*, 2012. Available at: http://www.bloomberg.com/news/2012-03-19/germany-s-270-billion-renewables-shift-biggest-since-war.html (accessed 15 November 2013).

O'Neill, R., 'Green jobs, safe jobs', *Hazards Magazine,* 2011. Available at: http://www.hazards.org/greenjobs/blog/#.Un0F86UTBg0

Ortegon, K., Nies, L. F. and Sutherland, J. W., 'Preparing for end of service life of wind turbines', *Journal of Cleaner Production*, Vol. 39, 2013, pp.191–199.

OSHA (Occupational Safety and Health Administration), G*eneral industry and construction training*. Available at: http://www.osha.gov./dte/outreach/index.html (accessed 17 August 2012).

Parkes, K. R., *Psychosocial aspects of work and health in the North Sea oil and gas industry*, HSE Research Report 002, prepared by the University of Oxford for the Health and Safety Executive, 2002.

Ponten, A., Carstensen, O., Rasmussen, K., Gruvberger, B., Isaksson, M. and Bruze, M., 'Epoxy-based production of wind turbine rotor blades: occupational dermatoses', *Contact Dermatitis,* Vol. 50, 2004, pp. 329–338.

Professional Engineering, 'Researchers seek out causes of failure in wind-turbine gear boxes', 2009, Vol. 22 (8), p. 44.

Public Health Department of Iowa, USA. ' Mobile tower crane falls 180 feet to the ground killing the crane operator', 2000, Iowa FACE program. Available at: http://www.public-health.uiowa.edu/face/reports/report-028.htm (accessed 11 April 2012).

Puigcorbe, J. and de-Beaumont, A., 'Wind turbine gearbox reliability, *Renewable Energy World Magazine*, 1 June 2010. Available at: http://www.renewableenergyworld.com/rea/news/article/2010/06/wind-turbine-gearbox-reliability (accessed 21 August 2012).

Raman, G., 'Wind turbines: clean, renewable and quiet?' *Noise & Vibration Worldwide,* Vol. 40, 2009, pp. 15–21.

Rasmussen, K., Carstensen, O., Ponten, A., Gruvberger, B., Isaksson, M., Bruze, M., 'Risk of contact allergy and dermatitis at a wind turbine plant using epoxy resin-based plastics', *International Archives of Occupational and Environmental Health,* Vol. 78, No 3, 2005, pp. 211–217.

Renewable Energy Focus. Retrieved 11 April 2012, from: http:www.renewableenergyfocus.com

RenewableUK, 'Approved training standard, issue 1: Working at height & rescue training — wind turbines', 2010a. 2012).

RenewableUK, *H&S guidelines: onshore & offshore H&S*, 2010b. Available at: http://www.renewableuk.com/en/publications/index.cfm/guidelines-for-onshore-and-offshore-wind-farms

RenewableUK, 'Medical fitness to work — guidelines for near offshore and land based renewable energy projects', *Health and Safety*, 2011a. Available at: http://www.bwea.com/pdf/safety/HS_Medical_Fitness_to_Work.pdf

RenewableUK, 'Lifts in wind turbines', 2011b. Available at: http://www.renewableuk.com/en/publications/index.cfm/Lifts-in-Wind-Turbines

RenewableUK, *H&S guidelines: vessel safety*, 2012. Available at: http://www.renewableuk.com/en/publications/index.cfm/vessel-safety-guide

RenewableUK, 'Offshore wind and marine energy health and safety guidelines', 2013: Issue 1.

Rodrigues, R. B., Mendes, V. M. F. and Catalao, J. P. S., 'Estimation of lightning vulnerability points on wind power plants using the rolling sphere method', *Journal of Electrostatics*, Vol. 67, 2009, pp. 774–780.

Rose, C., 'Where are the women in wind?', *Wind Directions*, April 2010, pp. 30–33. Available at: http://www.ewea.org/fileadmin/emags/winddirections/2010-04/pdf/WD_April_2010.pdf

Safety and Health Practitioner, 'Dermatitis sufferers not protected from resin', *SHP*, Vol. 27, No 7, 2009, p. 7. Available at: http://www.shponline.co.uk (accessed 21 August 2012).

Salzmann, D. J. C., Ampelmann, *Development of the access system for offshore wind turbines*. 2004. PhD thesis. Available at: http://www.we-at-sea.org/wp-content/uploads/2013/01/RL5-1-2004-012-Ampelmann-PhD-thesis.pdf

Shepherd, D., McBride, D., Welch, D., Dirks, K. and Hill, E. M. 'Evaluating the impact of wind turbine noise on health', *Noise & Health*, Vol. 13, No 54, 2011, pp. 333–339.

Siefert, H., Westerhellweg, A. and Kroning, J., *Risk analysis of ice throw from wind turbines*, DEWI, 2003.

Siltanen, E., Koponen, M., Kokko, A., Engstrom, B. and Reponen, J., 'Dust exposure in Finnish foundries', *Scandinavian Journal of Work and Environmental Health*, Vol. 2, Suppl. 1, 1976, pp. 19–31.

Small Wind Industry Implementation Strategy Consortium, *Acronyms & glossary of terms* (no date). Available at: http://www.hetronix.eu/files/050414ACRONYMS_GLOSSARY050409.pdf

Spinato, F., Tavner, P. J., Bussel, G. J. W. and Koutoutlakos, E., 'Reliability of wind turbine subassemblies', *IET Renewable Power Generation*, 2009, Vol. 3, No 4, pp. 387–401.

The Economist Technology Quarterly. 'Smart paint promises to make it easier to identify and repair cracks or corrosion in bridges and other infrastructure', March 2012.

Tossavainen, A., 'Metal fumes in foundries', *Scandinavian Journal of Work and Environmental Health*, Vol. 2, Suppl. 1, 1976, pp. 42–49.

Tveiten, C. K., Albrechtsen, E., Hegget, J., Hofmann, M., Jersin, E., Leira, B. and Norddal, P. K., *HSE challenges related to offshore renewable energy: A study of HSE issues related to current and future offshore wind power concepts*. SINTEF Technology and Society Safety Research. Report A18107, 15 February 2011. Available at: http://www.sintef.no/project/Nowitech/Publikasjoner/HSE%20challenges%20related%20to%20offshore%20renewable%20energy.pdf

United States Department of Labor, Occupational Safety & Health Administration (no date), 'Green job hazards: wind energy — falls', no date. Available at: http://www.osha.gov/dep/greenjobs/windenergy_falls.html (accessed 21 August 2012).

van Kooten, C. G. and Timilsina, G. R., *Wind power development — economics and policies*, The World Bank, Washington, DC, 2009.

Walsh, K. 'High wind load, high workload', *Cranes Today*, January 2011. Available at: http://www.cranestodaymagazine.com/features/high-wind-load-high-workload/ (accessed 11 April 2012).

Weinzettel, J., 'Life cycle assessment of a floating offshore wind turbine', *Renewable Energy*, Vol. 34, 2009, pp. 742–747.

Wind Power Engineering and Development, Lift assist "shortens" long ladders, February 15 2010. Available at: http://www.windpowerengineering.com/maintenance/safety/lift-assist-%E2%80%98shortens%E2%80%99-long-ladders/ (accessed 15 November 2013).

Wood, S., 'COSHH failures blow £35,000 off wind power firm's profits', *Health and Safety at Work, June* 2009. Available at: http://www.healthandsafetyatwork.com/hsw/content/coshh-failures-blow-%C2%A335,000-off-wind-power-firms-profits (accessed 15 November 2013).

Zakaria, A. and El-Maghrabi, G., 'Assessment of occupational exposures in foundries', *Journal of Egypt Public Health Association*, Vol. 78, No 3–4, 2003, pp. 245–264.

7 Appendices

7.1 Appendix 1: Search terms

- On shore Wind Energy
- Off shore Wind Energy
- On shore Wind Farms
- Off shore Wind Farms
- Renewables OR Emerging Energy Technologies
- Health + On shore OR off shore wind energy OR wind farms
- Safety + On shore OR off shore wind energy OR wind farms
- Health + Safety + On shore OR off shore wind energy OR wind farms
- Occupational Safety + Health + On shore OR off shore wind energy OR wind farms
- Safe design + onshore OR off shore wind energy OR wind farms
- Safety + Engineering tolerances + onshore OR off shore wind energy OR wind farms
- Safety + easy maintenance + recycling by designers
- Floating turbines + health + safety OR occupational health and safety + off shore wind farms
- Health + Safety OR occupational safety and health + manufacture + chemical exposure + wind turbines
- Health + Safety OR occupational safety and health + transportation + wind farm site + on shore OR off shore
- Safety + construction + wind farms + on shore OR off shore
- Health + Safety OR occupational safety and health + Operation of wind farms + access issues
- Health + Safety OR occupational safety and health + Operation of wind farms + ageing workforce
- Health + Safety OR occupational safety and health + Operation of wind farms + physically demanding roles
- Health + Safety + occupational safety and health + Operation of wind farms + slips and trips
- Health + Safety OR occupational safety and health + Operation of wind farms + falls from height
- Health + Safety OR occupational safety and health + Operation of wind farms + psycho social risks
- Health + Safety OR occupational safety and health + Operation of wind farms + working in isolation
- Health + Safety OR occupational safety and health + Operation of wind farms + living and working off shore
- Health + Safety OR occupational safety and health + Operation of wind farms + blade throw + blade shear + ice + blade fall
- Health + Safety OR occupational safety and health + Operation of wind farms + fires
- Health + Safety OR occupational safety and health + Operation of wind farms + emergency arrangements
- Health + Safety OR occupational safety and health + On shore OR off shore wind farms + integration with grid

- Health + Safety OR occupational safety and health + On shore OR off shore wind farms + electric cables from turbines
- Health + Safety OR occupational safety and health + Off shore OR on shore + construction of substations
- Health + Safety OR occupational safety and health + Offshore wind farms + diving safety
- Health + Safety OR occupational safety and health + Off shore OR on shore + construction of large DC cables from off shore to land
- Health + Safety OR occupational safety and health + maintenance of on shore + off shore + access issues + ageing workforce + physically demanding role + slips and trips + falls from height + psychosocial risks + working in isolation + living and working off shore
- Health + Safety + Land Use Planning
- Health + Safety + Off shore OR onshore + Extreme Weather Conditions OR Poor Weather Conditions OR Bad weather
- Health + Safety OR occupational safety and health + migrant workers + temporary workers + subcontractors + subcontractorisation
- Health + Safety OR occupational safety and health + decommissioning on shore OR off shore wind farms
- Health + Safety OR occupational safety and health + re-powering/life — extension on shore/off shore wind farms + access issues + ageing workforce + physically demanding role + slips and trips + falls from height + psychosocial risks + working in isolation + living and working off shore
- Health + Safety OR occupational safety and health + decommissioning onshore OR off shore wind farms
- Health + Safety OR occupational safety and health + recycling and waste management + reuse of turbine components
- Wind farms OR Wind Energy + psychosocial risk factors + fatigue + job demands + control + ageing + sleep patterns + working in isolation + stress + wellbeing + support from supervisor OR manager OR colleagues + job content + workload + work pace + work schedule OR shift working OR night shifts OR inflexible work schedules OR unpredictable hours OR long hours OR unsociable hours + control OR low participation in decision making OR lack of control over workload OR pacing + environment and equipment OR inadequate equipment availability OR suitability + maintenance OR poor environmental conditions OR lack of space OR poor lighting OR excessive noise + organisational culture OR poor communications OR low levels of support for problem solving OR personal development OR lack of objectives + social + physical isolation OR poor relationships with managers OR supervisors OR superiors + interpersonal conflict + lack of social support + bullying + harassment + role ambiguity OR role conflict + work life balance

7.2 Appendix 2: Wind energy life cycle

Design

Safe design, for example engineering tolerances, access consideration, sitting of power cables, emergency access considerations, easy maintenance and recycling by design.

Development

New concept designs, floating turbines, larger turbines and specific offshore designs.

Manufacture

Chemical exposure during manufacture, movement of heavy objects, slips and trips, musculoskeletal disorders (e.g. repetitive movements, awkward postures).

Transport

Transport from manufacturing site to wind farm site onshore or to port and offshore sites.

Construction

Partial assembly in port, foundation construction offshore, turbine construction onshore.

Operation

Access issues, ageing workforce, physically demanding role, slips and trips, falls from height, musculoskeletal disorders, psychosocial risks including isolation, living and working offshore, blade throw, ice throw/fall, fires, emergency arrangements, structure failure, exposure to dust and dangerous substances, emergency arrangement.

Associated infrastructure

Integration with the grid. Electric cables from turbines, construction of on/offshore substations, construction of large DC cables from offshore to land.

Maintenance

Access issues (on- and offshore), ageing workforce, physically demanding role, slips and trips, falls from height, musculoskeletal disorders, psychosocial risks including isolation, living and working offshore, and ice fall structure failure, exposure to dust and dangerous substances, emergency arrangement.

Repowering/Life extension

Access issues (on- and offshore), ageing workforce, physically demanding role, slips and trips, falls from height, psychosocial risks including isolation, living and working offshore.

Decommissioning

Recycling and waste management and reuse of turbine components

Source: HSL (2012) adapted from D'Souza, Gbegbaje-Das and Shonfield (2011).

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