OCCUPATIONAL SAFETY AND HEALTH IN THE WIND ENERGY SECTOR

1 Introduction

This e-fact considers occupational safety and health (OSH) issues in the wind energy sector and is aimed at raising awareness and supporting good OSH in onshore and offshore facilities. It summarises the findings from EU-OSHA's report 'Occupational safety and health in the wind energy sector' (EU-OSHA, 2013a). It considers the activities associated with wind energy and identifies specific hazards to workers across the entire life cycle of wind turbines, from the design and manufacturing of parts, through their transport, installation and maintenance, to emergency rescue and waste treatment. 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 deaths, serious injuries and ill health during the various phases of a wind farm project. 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 (e.g. working at heights, manual handling, electrical risks or confined spaces) the working environments and combinations in which they are found create unique challenges (e.g. remote areas, extreme weather conditions or working at sea). 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, 2013b).

1.1 Wind energy sector

The production of energy accounts for 80 % of all greenhouse gas emissions in the European Union (EU). In its Europe 2020 Strategy (European Commission, 2010), the European Commission has committed to reducing its greenhouse gas emissions by at least 20 % by 2020, to improving energy efficiency by 20 % by 2020 and to increasing the share of renewable energy to 20 % by 2020.

Wind energy is renewable and clean, and produces no greenhouse gas emissions. Europe has an ambitious challenge to increase its wind energy capacity so that it represents 25 % of EU electricity consumption by 2030 (EWEA, 2010). In 2012, it accounted for 13 % of the EU's power capacity and 32 % of all new power capacity in Europe (EWEA, 2014). 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.

In 2010, there were 70,488 onshore wind turbines and 1,132 offshore turbines across the EU (EWEA, 2013a). By the end of 2009, the European wind energy sector provided 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, 2012).

Growth in the wind energy sector can be attributed to a number of factors, including financial confidence, technological advances, 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, OSH becomes a prime concern. 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 therefore putting their safety and health at risk.

1.2 Wind energy turbines

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.

Wind turbines are installed both onshore, including inland and costal installations, and offshore, 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 1: 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. Most commercial wind turbines have three rotor blades.

Figure 1: Common components of a wind turbine: (1) tower, (2) blades, (3) hub and (4) nacelle. Left: onshore wind turbines. Right: offshore wind turbines.

Left: onshore wind turbines

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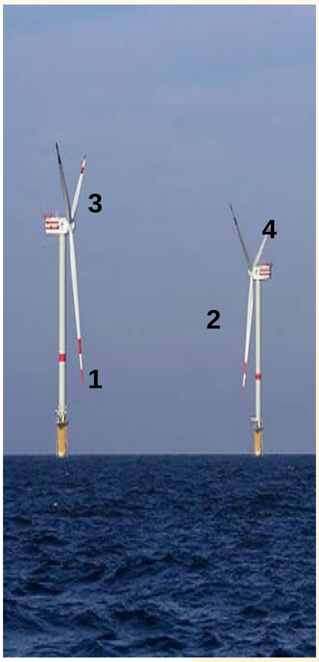
Author: Leaflet

Right offshore wind turbines



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Offshore wind turbines and farms are larger than their counterparts on land, and, as a result, the electricity production of each turbine is higher. 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 transport and installation equipment can accommodate larger and heavier components for offshore wind farms.

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.

1.3 Legislation

Other than the Renewable Energy Directive (2009/28/EC), there is no legislation specific to the wind energy sector. However, other directives applicable to OSH do come into play at various stages of the life cycle.

The Framework Directive (89/391/EEC) lays down the obligation of the employers to evaluate the risks to the safety and health of workers. It contains the general principles of prevention that would be applicable to work being undertaken in the wind energy sector such as the elimination or the substitution of hazards, the use of engineering and administrative controls, the use of personal protective equipment as a last resort and the informing, consulting and balanced participation and training of workers and their representatives.

Other European legislation related to undertaken in wind turbines include:

- EU Directive 2009/104/EC concerning the minimum safety and health requirements for the use of work equipment by workers at work.
- EU Directive 2006/42/EC on machinery.
- EU Directive 96/53/EC laying down for certain road vehicles circulating within the EU the maximum authorised dimensions in national and international traffic and the maximum authorised weights in international traffic.
- EU Directive 98/24/EC on risks related to chemical agents at work.
- EU Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work.
- EU Directive 90/269/EEC on the minimum health and safety requirements for the manual handling of loads where there is a risk particularly of back injury to workers.
- EU Directive 92/57/EC on the implementation of minimum safety and health requirements at temporary or mobile construction sites.

2 General challenges to OSH 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.

It could be argued that the hazards found within a wind farm are not very different from those that exist in other industries today. However, considering the sometimes unique and extreme conditions in which these hazards are found, 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, 2013b).

Several common challenges have become apparent with regard to OSH in the wind energy sector and these have been outlined below.

2.1 Lack of OSH data and information

It is evident that the amount of information available related to OSH is rather sparse and in some cases extremely vague. The main reasons for this lack in OSH data within the wind energy sector are:

- 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.

- The operational data of turbines are kept confidential by the manufacturer. Some wind energy operators share among 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 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, with other industries and with OSH actors and researchers. This would help to improve both OSH standards and working conditions for their workers. It has also been suggested that, for the less mature offshore industry, it might be helpful to conduct further research on wind farms to identify the OSH issues and the level and type of risk assessment that is required.

Some of the areas where additional information is needed are detailed in the following sections.

2.1.1 Statistics on accidents and work-related diseases

Data on accidents and work-related diseases in the wind energy sector are hard to find and usually the information available is not very comprehensive. The report on which this e-fact is based gathers OSH-related material in the wind energy industry by using data from national wind energy trade bodies and other stakeholders. Some national wind energy associations do collect and publish accident statistics, for example:

- In 2013 RenewableUK replaced its lessons-learnt database with the Renewable Industry Safety Exchange system (RISE; see: http://www.renewableuk.com/en/our-work/health-and-safety/incidents--alerts.cfm). 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, the Spanish wind energy association, collects information from participating companies, the number of which increased from 12 in 2007 to 40 in 2012 (AEE, 2013).

These services confirm that over the past few years there has been an upward trend in the number of accidents occurring in the wind energy sector. As more turbines are built, more accidents occur.

2.1.2 Gender aspects

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 exclude themselves from, fieldwork within the wind energy industry.

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 effects on their reproductive systems, 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 effects on the health of women at work. This should include the prevention measures that need to be implemented in order to protect both men and women from health hazards throughout the life cycle of wind turbines.

2.1.3 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 towers or working in confined spaces for long periods of time, which may have an impact on health and may in turn affect the ability of older workers. As an example, as technicians descend down a wind turbine ladder there is an increased impact to their body and this results in more shocks to the ankles and knees. Despite the relative good pay, many workers stay on the job only three to four years (Dvorak, 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.

2.1.4 OSH data and research on the impact of wind energy

Over the years a number of reviews and reports have focused on the evidence of the health and safety impacts of wind farms, but they mostly 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 evidence of the impact that these same issues could have on workers is not available. 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 the wind industry is a safe and responsible environment 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.

2.2 Skills shortage and training

Considering that the core parts of the wind energy sector are only about a decade old, experts, or a workforce of any size, are still thin on the ground. The rapid development of the wind energy sector over the past few years has resulted in severe skill shortages. This shortfall in skilled workers could climb to 18,000 by 2030 and this accounts for nearly 5 % of the entire wind energy industry workforce (EWEA, 2013b). The existing skills gap is at 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.

Wind energy cannot compete with the 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 factors contributing to this shortage in skilled 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. Small and medium-sized companies find it more difficult 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). Still, wind energy specific training would enable the transition of technical skills to the needs of the wind energy industry.

Wind energy employers want to see more standardised programmes and the harmonisation of training certification that would reduce costs and wasted time and also increase the mobility of the wind energy workforce. There has been significant investment and work done to try and develop wind-specific training integrating OSH aspects in Europe; for example, 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 (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;
- crane signal and rigging practices;
- safe manual handling;
- working at height
- working in confined spaces;
- fire awareness; and
- offshore survival.

2.3 Procedures and standards

The lack of recognised harmonised standards and guidelines for the safe operation of wind farms, particularly for offshore facilities, was highlighted in EU-OSHA's report. For a long time many countries have not required 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.

There are standards on performance, product, and testing, sampling and analysis; the IEC 61400 series, for example, gives a set of design requirements. However, there are no standards addressing general issues, certification, operation, manufacturing, sustainability or training skills and qualifications.

Without clear guidance in place, associations such as the European Wind Energy Association (EWEA), together with trade bodies at the national level, including RenewableUK and the G9 Offshore Wind Health and Safety Association, 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.

An important development in the wind energy sector is the planned update to the European standard BS EN 50308:2004 (Wind turbines: Protective measures — requirements for design, operation and maintenance). 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.

3 OSH issues across the life cycle of a wind turbine

Wind energy workers both onshore and offshore may be exposed to OSH risks throughout the entire life cycle of a wind turbine. It is not unusual for the majority of workers in the wind energy sector, whether onshore or offshore, to work at height, climb ladders many times a day, work in confined spaces in awkward positions, expend great physical effort or be exposed to chemicals, fumes and dust. These working conditions all lead to many OSH hazards. However, the offshore working environment introduces additional hazards or an increase in risk to the workers when undertaking or being exposed to:

- Personnel transfers — there are hazards during personnel transfers between marine vessels or helicopters and wind turbines, risk of collisions and falls into water by workers.
- Diving operations — there are hazards during foundation installation, cable laying, turbine inspections and maintenance.
- Emergency evacuations — evacuations during a fire, explosion or severe weather conditions are more difficult. The travel distance to and from shore during emergencies needs to be considered.

- Exposure to weather conditions and heat and cold — offshore platforms are subject to more extreme weather conditions. Changes in weather or shipping delays also lead to time pressure and constraints. Workers can end up stranded for days.
- Structural risks — wave action, currents and corrosion will affect turbine components.
- Lifting operations — offshore turbines are larger and the wind loads are greater because of the extreme weather conditions. There is a risk of movement of the vessel during lifting and motion of the turbine.

3.1 Hazards at each stage of the life cycle

Hazards to workers' safety and health related to wind farm development can occur during any of the major phases of a wind farm project.

3.1.1 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, and is relevant in the development of new technologies, processes and materials in the wind energy sector. This is a concept that should be promoted as a cost-effective means of preventing or reducing work-related accidents and health problems and enhancing OSH within the sector.

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 hazardous 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, 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 the number of falls from height and musculoskeletal problems because they can simplify some of the more difficult tasks (EWEA, 2010; EERA, 2010; Byon, 2010). The longer design lives of some components in wind turbines also improve the OSH of workers simply because they spend less time working in and around them on unscheduled maintenance tasks. Ultimately, there will be situations when a visit is unavoidable; the design should therefore allow technicians to deal with any issues safely and quickly. However, in an effort to make efficiencies, some potential OSH implications may have been overlooked. One such example is the use of nanomaterials in smart paint. Smart paints were developed to help reduce weathering effects on wind turbine components. The conductivity of the paint 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. There is some evidence that some types of carbon nanotubes may have asbestos-like effects.

The suitability of the lifts that are currently being installed in many tall turbines is another issue of concern. There is currently no European standard for turbine lifts. Although, with the growing size of turbines and the increasing number of turbines installed in the EU, the benefits of providing lifts are acknowledged, it is suggested that the lifts currently being installed may not comply with the requirements of Directive 2009/104/EC (use of work equipment). The need to manage working at heights has forced wind turbine operators to consciously consider the practicalities of lift installation. Without a specific turbine lift standard, the safe use of work equipment Directive 2009/104/EC 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. 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 to electrical, fire and emergency rescue safety being compromised (RenewableUK, 2011).

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).

3.1.2 OSH risks associated with the manufacture of wind turbines

The manufacture of wind turbines and all its components accounts on its own for nearly 60 % of all workers within the wind energy sector. 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 found focuses on the exposure to hazardous chemicals. The chemicals most routinely referred to are epoxy-based resins and glass-reinforced plastic (GRP).

- 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 metres long.

Of all the manufacturing activities identified, work undertaken on the turbine blades is the one that exposes workers the most to hazardous substances. 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, sanding down any imperfections and painting as required. Other clusters were found in the blade shell unit, where moulds for 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.

In addition to chemical hazards from exposure to epoxy resins, styrene and solvents, other harmful gases, vapours and dusts created during the manufacture process must be considered. 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 effects on the reproductive system.

Newer manufacturing plants may invest more in up-to-date production processes such as robotic spraying booths or vacuum-assisted resin transfer moulding that will reduce the exposure of workers to dangerous substances and immediate contact with them; 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.). Offshore wind turbine production and installation activities are increasingly being undertaken at new port facilities. This trend 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. Further work could be done to assess the musculoskeletal issues that may occur as a result of the increased size of these components.

3.1.3 OSH risks associated with transporting wind turbine components and workers

Moving enormous wind turbine components for hundreds of kilometres is more than a substantial logistics challenge for the wind energy sector. It also poses a number of OSH concerns for the workers involved. Although most road accidents involve turbine sections falling from transporters — for example, in one incident a 45-metre turbine section rammed through a house while being transported — 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 side roads. Offshore transport introduces additional issues, such as the transport 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 and pitching. To ensure the safe transport 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 need for escorts, contingency planning, restricted access routes, steep gradients, confined road corridors, road traction, limited turning points or forms of communication that will be needed. Furthermore, a swept path analysis should be undertaken before the transport to anticipate and avoid any dangerous situations.

The change towards the manufacture of offshore components at ports will reduce some of the road transport issues; however, as offshore wind turbines are being sited further away from the shore, the travelling distance required by workers at sea is increasing. It is important to remember that it is not just the OSH implications of transporting components that require 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 whole body vibration (WBV), which is usually caused by travelling in unsuitable craft in rough seas. The selection of vessels for transport (EWEA, 2009) is important to ensure that workers complete their journey safely and that WBV and the resulting fatigue and discomfort are minimised to avoid any 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 considers 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 consequent risks associated with vibration that may cause fatigue or discomfort (e.g. sea sickness), which may impact on capability and safety (RenewableUK, 2012).

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 in 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.

3.1.4 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.

Some of the hazards encountered during the construction phase of wind farms include:

- falling structures, loads or objects during lifting operations;
- falls from heights;
- mechanical hazards, such as contact with moving parts;
- electrical hazards — short circuits, overcharge, electrostatic phenomena or falls due to shock;
- fire or explosion of turbine (use of combustible materials) or vessel;
- manual handling of heavy turbine components;
- ergonomics hazards — fatigue from climbing ladders or working in confined spaces, or physiological effects caused as a result of heavy lifting and repetitive movements;
- 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 hazards — 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;
- the challenging evacuation of persons from wind turbines as a result of changing weather conditions and locations; and
- offshore hazards — marine operations and transportation, for example ship collisions or man overboard.

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.

Operations both on land and at sea 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 metres 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.

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.

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 not only during the construction phase, but also during the operation, maintenance and decommissioning stages. For example, a 19-year-old construction worker was killed after falling 30 metres 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 workers. 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 an 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.

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.

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 in the offshore construction and installation of the wind turbines. The majority of works, for example design, construction, installation and commissioning, are generally undertaken by contractors. 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 will never have worked in the wind energy industry, particularly offshore. Successful management of the project will therefore depend on:

- the appointment of suitable competent persons for key safety-related roles;
- appropriate contractor selection, considering the safety culture and ensuring that the contractor's investment in developing competent people and safe methods brings a competitive advantage, rather than just considering 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.

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.

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

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 are exactly the same. Some of the operational failures that personnel working in or around a wind turbine could be exposed to include:

- tower collapse;
- blade failure;
- tower strike;
- fire;
- lightning strike.

Weather is a 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 expected.

Although offshore wind farms share some of the risks found in 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 inspections and maintenance. As the turbines can be accessed only by boat or helicopter, the ability to reach the turbines is highly dependent on the state of the sea. 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.

There are very 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 decibels 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. Wind turbine noise between 35 and 50 dBA can be associated with sleep interruption among people living less than 2.5 kilometres 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 decibels (dB). The health effects from long-term exposure to low levels of low-frequency noise are unknown, 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.

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 mean 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 varied 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. 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 metres high) when either there is 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.

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. If frequent maintenance is required, 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 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. 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.

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 or turbine to be maintained and the specific challenges associated with its location. If reactive maintenance is required, it is recommended (RenewablesUK, 2010) that consideration be given to weather working limits; the availability of sufficient light for operatives to work safely if night working is required; the availability of appropriate personal protective equipment depending on the tasks to be undertaken and location; and emergency procedures.

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 design out operational and maintenance OSH risks of which we are now aware, 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.

3.1.6 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 undersea 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 they are damaged, the subsequent repair work will increase offshore risk exposure (RenewableUK, 2013).

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 typically involves a tension of several tonnes; pulling a cable across or under a beach, for example, would involve a much higher tension. If any equipment breaks or becomes 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, thereby 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, which will be subject to induced voltages from other cables that run parallel or are in close proximity.

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.

3.1.7 Repowering and decommissioning

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 as well as 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 with 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 to 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, 2013b).

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. Although 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.

Technological advances 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 expected that in the coming years there will be an increased level of decommissioning activity and, with that, associated OSH risks. The OSH risks associated with the end stages of a component's 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 as may cause hazards in the construction and installation stage. The designs for these installations are unlikely to have considered their legacy, how they will be dismantled and the recycling of their parts. 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). 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 corrosion may cause failures and safety concerns during wind turbine decommissioning.

Inevitably, most of the decommissioning 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.

3.1.8 Waste management 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; however, turbine blades that are manufactured almost entirely 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 ways to dispose 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 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 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 waste-handling practices for rotor blades and their OSH implications for workers are unknown.

4 Future challenges

OSH, and how it is maintained and improved, is a very important issue in the wind energy sector. As the sector develops over the next few years, there is a need to ensure that OSH continues to be implemented and that high safety standards are maintained. The tightening up of OSH in the wind energy sector will improve the protection of the workers in the industry and will also improve the reputation of wind power.

The importance of working together to spread information and bring down the level of risks across the industry is paramount. Some of the challenges that the wind energy sector will have to address when developing and improving their OSH levels will include:

Communication: the need to have strategies in place that will allow all workers, contractors or visitors to be kept informed and up to date with OSH information, for example what to do in case of an emergency or accident.

Sharing information: OSH information needs to be shared better. The more OSH information is shared (for example accident statistics), the more companies and organisations can learn from each other's experiences and this will help to improve OSH standards and working conditions. Keeping a sensible and constructive discussion going is important to achieve the most effective OSH regime.

Training: standardised programmes and the harmonisation of training certification (which would include the dissemination of appropriate educational content and techniques to industry) would reduce costs and wasted time and also increase the mobility of the wind energy workforce. Workers with the correct level of OSH training will be safer than those with substandard levels. This training needs to be effective and understandable and should be provided to all workers, including clients and contractors.

Competence: OSH training is an important component of OSH in the workplace; however, this will be effective only if workers understand the training received and the instructions provided. Ways of checking the OSH competence of the workforce, including contractors, should be in place.

Design: many of the OSH risks in the wind energy sector come from the design stage. Design is a critical stage in minimising the potential for OSH issues throughout the life cycle of wind turbines. With prevention through design, OSH will be incorporated into the design at the very earliest stages of a wind farm project and this will allow the 'designing out' of hazards and risks and help to prevent or minimise work-related accidents and ill health in the sector. The industry should be designing systems to be safe, not adapting a design to make it safe.

Harmonising procedures and guidelines: having companies and organisations that speak the same OSH language will lead to a smooth transfer of workers on an international level, wasting less time and money. Working to harmonised guidelines means that companies can work better together and this will lead to an improvement in best practices across the industry.

Boosting recruitment: the expected shortfall in skilled workers entering the industry is a big OSH concern, since many of the workers who are prepared to join the industry have little or no experience of the OSH challenges they will face when working on wind turbines. A number of actions will be required to boost employment and address the skill shortage (Boettcher et al., n.d.). This could include seeking to attract new talent by levelling the playing field with other competitive sectors such as oil and gas; effective marketing of career paths that are both challenging and fulfilling, to increase the attractiveness of the sector; or investing further in education, perhaps through the provision of university grants for engineers.

Waste management: wind energy needs to ensure that poor planning does not defeat the renewable goals. When a turbine is operating, it produces green energy but once it is decommissioned it suddenly becomes a problem, since materials used (such as carbon fibre composite, a key material in wind turbine blades) cannot be recycled. Since 2004, most EU Member States have passed laws forbidding landfill disposal of carbon fibre composites. Further, incineration of plastics is discouraged because of the potential release of toxic by-products. Because the design phase of these wind turbines did not consider the implications of materials used, the greatest challenge now is to develop a profitable and safe recycling process for the unwanted carbon fibre blades. Another waste management concern is the current use of nanomaterials.

The use of nanomaterials creates potential issues for workers involved in waste management and recycling work, since they could be exposed to paint or dusts containing carbon nanotubes or other nanomaterials. To avoid these OSH risks in the later stages of the wind turbine life cycle, it is important that the future implications of these waste materials be considered at the design stages.

Further research

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.

Given the lack of data on the exposures of workers to risk (most research so far has focused on public safety), more occupational-based research is required so that the wind energy sector is seen as a safe and responsible sector in which to work.

Research is needed, in particular, on areas such as:

- the impact of work activities on the long-term career and health of all workers in this industry;
- musculoskeletal issues that may occur as a result of the increased size of components in the manufacture of turbines;
- new combinations of traditional risks in new environments, including noise, vibration, electromagnetic radiation, use of dangerous substances, vibroacoustic disease and wind turbine syndrome;
- the use of nanomaterials and possibly other new substances with unknown health impact in this sector; and
- waste handling for rotor blades.

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