VECTORS of Change in Oceans and Seas Marine Life, Impact on Economic Sectors

SP1 - Cooperation
Collaborative Project - Large-scale Integrating Project
FP7 – OCEAN - 2010
Project Number: 266445

Deliverable No: 60.5  Workpackage: 6

Date: 31-03-2014  Contract delivery due date  Month 38

Title: Develop Risk assessments leading to Best Practice: Resource Exploitation – Renewable Energy

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Dissemination level (PU=public, RE=restricted, CO=confidential) PU

Report Status (DR = Draft, FI = FINAL) DR

Acknowledgements
The research leading to these results has received funding from the European Community’s Seventh Framework Programme (FP7/2007-2013) under Grant Agreement No. [266445] for the project Vectors of Change in Oceans and Seas Marine Life, Impact on Economic Sectors (VECTORS)
VECTORS Overview

‘VECTORS seeks to develop integrated, multidisciplinary research-based understanding that will contribute the information and knowledge required for addressing forthcoming requirements, policies and regulations across multiple sectors.’

Marine life makes a substantial contribution to the economy and society of Europe. In reflection of this VECTORS is a substantial integrated EU funded project of 38 partner institutes and a budget of €16.33 million. It aims to elucidate the drivers, pressures and vectors that cause change in marine life, the mechanisms by which they do so, the impacts that they have on ecosystem structures and functioning, and on the economics of associated marine sectors and society. VECTORS will particularly focus on causes and consequences of invasive alien species, outbreak forming species, and changes in fish distribution and productivity. New and existing knowledge and insight will be synthesized and integrated to project changes in marine life, ecosystems and economies under future scenarios for adaptation and mitigation in the light of new technologies, fishing strategies and policy needs. VECTORS will evaluate current forms and mechanisms of marine governance in relation to the vectors of change. Based on its findings, VECTORS will provide solutions and tools for relevant stakeholders and policymakers, to be available for use during the lifetime of the project.

The project will address a complex array of interests comprising areas of concern for marine life, biodiversity, sectoral interests, regional seas, and academic disciplines and especially the interests of stakeholders. VECTORS will ensure that the links and interactions between all these areas of interest are explored, explained, modeled and communicated effectively to the relevant stakeholders. The VECTORS consortium is extremely experienced and genuinely multidisciplinary. It includes a mixture of natural scientists with knowledge of socio-economic aspects, and social scientists (environmental economists, policy and governance analysts and environmental law specialists) with interests in natural system functioning. VECTORS is therefore fully equipped to deliver the integrated interdisciplinary research required to achieve its objectives with maximal impact in the arenas of science, policy, management and society.

www.marine-vectors.eu
Executive Summary

This report forms D60.5 of the VECTORS project, and builds on information provided by WP1 on energy demands and new technologies (D1.1 and D1.2), WP4.2 which focuses on North Sea research, and WP6 on policy and stakeholders (D6.1). The aim of this deliverable is to assess the efficacy of marine planning in minimising risk in the context of wind farm developments in the North Sea. VECTORS has used the Bow Tie method to assess risk in particular case study scenarios in order to test the appropriateness of this approach for future use by stakeholders / managers in marine planning with the aim of recommending a suitable future methodology. This work is closely linked to D60.3 and D60.4 which provide risk assessments for ballast water and fisheries respectively, with all three risk assessment deliverables feeding into D60.6 policy and governance synthesis and D60.7 online synthesis of VECTORS for stakeholders and policymakers.

Risk Analysis that considers everything concerning offshore energy is a complex task, hence the case study of offshore wind power on the Dogger Bank in the North Sea was chosen as an example of an area primed for large scale wind development in the near future. It is proposed that lessons learned from this case study are relevant to all other European marine areas. Hence, the Bow Tie method for the analysis for risk assessment and management was chosen to help determine whether this form of analysis would work for such an intricate case, in order to assess the efficacy of marine planning in managing risk and determine risk minimisation procedures. Under the umbrella of future climate change, the top-level ways in which the environment could affect the successful operation of the wind farm and the use of the wind resource were examined, as were the ways that the wind farm may affect the environment in the context of the Marine Strategy Framework directive (MSFD) descriptors of Good Environmental Status (GEnS).

Use of the Bow Tie approach has been successful in being able to map out all aspects that are related to a particular event that we do not want to happen, including ways of preventing and mitigating risk. In this case these two events have been:

1) the loss of renewable energy resources; the context of this Bow Tie was: ways that climate change can cause the environment to affect the wind farm;

2) changes to the environment in terms of the MSFD GEnS indicators; the context of this Bow Tie was: ways that the wind farm can affect the environment.

A strength of the Bow Tie program is that complex information can be included in clickable boxes, as can links to relevant documentation. The software is more than just the diagram that can be printed out. It is possible to make the analysis quantitative if probability information exists for the hazard under study as well as to incorporate the principles of DPSIR by creating chained and nested Bow Tie diagrams to give a full overview of a system, at various ecological scales. Different levels of depth will be needed by different levels of an organisation, therefore the Bow Tie program serves a multifaceted purpose whereby the diagrams are sufficient by themselves to disseminate to those who may only need to know the top-level outcome, this may be the public or the media. Those members of the organisation implementing changes and working on the logistics of the wind farm development can access all of the deeper information to help make more informed decisions and improve and edit the risk assessment as more information becomes available.

A potential drawback is the apparent linear nature of the diagram. Sometimes not all mitigation or prevention measures are needed, or sometimes more than one may be applied simultaneously. This is
not evident from the diagrammatic format of the Bow Tie Risk Assessment and may be misleading for those not familiar with the Bow Tie scheme.

The current deliverable is a top-level risk assessment that attempts to encompass the entire system. If Bow Tie was chosen to be used as a complete risk management method then more precise Bow Ties could be constructed that allow different aspects of the system to be analysed in a greater level of detail. As our knowledge and understanding of the impacts caused by and to wind farms progresses, the contents and prominence of risk assessments will change and the Bow Tie can be quickly adapted to accommodate these. Furthermore, the Bow Tie value and use is increased by adding quantitative elements should such information become readily available.

Although this exercise has been considered to be successful as a proof of concept and has shown that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to wind energy in the North Sea, further development is needed to determine the overall significance or acceptability of the causes and consequences.
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Pressures on Marine Ecosystems: wind power

The worldwide growth of wind power

In recent decades, increasing emphasis has been placed on the negative effects of generating energy from non-renewable sources for example the burning of fossil fuels such as oil and gas, and nuclear power generation. Incidents such as the Fukushima nuclear reactor coolant failure in 2011, the 2005 Sellafield leak and the 1986 Chernobyl disaster have raised concerns over the safety of nuclear power, and the atmospheric and environmental effects of burning fossil fuels have been extensively studied and the negative impacts (acid rain, ozone depletion, greenhouse effect, ocean acidification etc) are well known (Anastasi et al., 1990; Bates and Peters, 2007; Cape, 1993; Irwin and Williams, 1988; Turley et al., 2010; Wuebbles and Jain, 2001). Burning of fossil fuels plays a central role in the climate change debate (IEO, 2011). Additionally, an increasing global population means that the demand for energy is expected to treble by 2050 (WEC, 2012) and the global energy-related carbon dioxide emissions are predicted to increase from 30.2bn metric tonnes in 2008 to 43.2bn t by 2035 (IEO, 2011). However, despite these factors, in 2009 the UK consumed only 3% of its energy from renewable sources whereas the EU 2009 Renewable Energy Directive set a target for the UK to achieve 15% of its energy consumption from renewable sources by 2020 (see, Directive 2009/28/EC).

When compared with traditional forms of energy generation such as the burning of fossil fuels, or nuclear power, renewable energies such as wind have several advantages. Firstly the energy produced is clean (no smoke, greenhouse gases, radiation or other volatile compounds are produced). As there is no combustion or fission there is also no need for coolant systems as with traditional power stations. Renewable technology is also relatively safe from a health and safety point of view (nothing to explode, no chance of nuclear disasters or radiation leaks). Offshore wind power has been regarded as being environmentally benign (Wilson et al., 2010).

Offshore wind turbines operate in the same manner as land-based wind turbines, however siting a wind farm at sea has several advantages over an on-shore site including more available space and less adverse reaction from the public regarding noise and visual intrusion. Additionally, the offshore wind fields are generally stronger, more consistent and much smoother than wind over land (Sun et al., 2012).

Although the offshore wind industry has existed only since the early 1990s, it is increasing globally and worldwide wind power generation has doubled approximately every three years (Ackermann and Söder, 2002; Dincer, 2011). In the early and mid-1980s when wind power first started being used on a commercial scale, the typical wind turbine size was less than 100 kW. By the late 1980s and early 1990s, turbine sizes had increased from 100 to 500 kW and then to 2.5 mW by the turn of the century. Turbines now have capacities up to 3.5 mW (Joselin-Herbert et al., 2007) and with continuing advances in technology capacity is expected to increase further. By the end of 2010 there were 84 GW of wind energy installed in the European Union (Gruet, 2011) (Figure 1). There is a European potential for a further 40GW of offshore installed capacity by 2020, with an additional 110GW installed by 2030; in the US 54GW by 2030 and in China 30GW by 2020 (EWEA, 2011).
Pressures and potential implications

Increasing global population is increasing demand on natural resources and ecosystems which generally degrades the ecosystem. In the European Union, the assessment, management and protection of marine ecosystems is aimed to be achieved through the implementation of the Marine Strategy Framework Directive (Directive 2008/56/EC). This requires Good Environmental Status to be achieved according to 11 Descriptors (Borja et al., 2013):

Descriptor 1: Biological diversity
Descriptor 2: Non-indigenous species
Descriptor 3: Population of commercial fish / shell fish
Descriptor 4: Elements of marine food webs
Descriptor 5: Eutrophication
Descriptor 6: Sea floor integrity
Descriptor 7: Alteration of hydrographical conditions
Descriptor 8: Contaminants
Descriptor 9: Contaminants in fish and seafood for human consumption
Descriptor 10: Marine litter
Descriptor 11: Introduction of energy, including underwater noise
The potential impacts of all offshore wind farms will fall into some or all of these categories at all life stages of the project (construction – operation – decommissioning) (Wilson et al., 2010). Understanding of the potential implications of large scale offshore wind farms has not increased in line with the recent increase in the number of developments (Drewitt and Langston, 2006). In addition, although current offshore wind technologies build upon existing onshore wind technology, the industry by comparison remains relatively immature. By nature, offshore wind farms are located in remote areas and operate under the harshest weather conditions, hence robust offshore technology is needed to ensure the safety, reliability and survivability of such installations (Sun et al., 2012).

Nearshore habitats are biologically both diverse and productive (Madsen et al., 2006), hence the construction and operation of renewable energy projects such as marine wind farms raises concern about the potential effects on the uses and users of the marine environment such as fishing and tourism (Atkins et al., 2011). As construction of offshore wind farms is only now occurring on a large scale, the impacts are unknown but are assumed to be broadly similar to those that occur inshore. The cumulative impacts of several wind farms operating in one area, or several anthropogenic activities operating in and around a single wind farm (or wind farm group) is also a largely unexplored topic. However options such as co-locating activities e.g. aquaculture and wind farms has been suggested as a way of reducing spatial demands (Christie et al., 2014), and wind farms are known to have the potential for habitat creation by introducing a hard substratum that may attract fish and crustaceans of commercial value (Bohnsack and Sutherland, 1985; Langhammer and Wilhelmsson, 2009; Maara et al., 2009; Wilson and Elliott, 2009). Careful siting of wind farms should be able to minimise most possible nature conservation impacts (Drewitt and Langston, 2006; Wilson et al., 2010) and appropriate risk assessment and management will play a key role in this.

Risk assessment, overview

Risk assessment (RA) has long been used by industries where there is potential for serious consequences of malfunction or accident, for example, nuclear, aviation, space exploration, oil, rail and military, as a means of reducing and mitigating risks (Cormier et al., 2013). For example, to minimise the likelihood of a bird-strike which can cause engines to fail, before planes take-off at airports, birds resting around the runway are scarred away. Similarly, where errors have the possibility of affecting human health, such as in the medical and food industries, activities are controlled and risk assessments performed on a continual basis. In order to understand and perform a RA, certain basic concepts must be defined:

- **Hazard**: the potential that there will be damage to a human asset/activity, or to the environment;
- **Risk**: the amount of asset/activity/environment etc that may be affected (Elliott et al., 2014).

The UK Department for Environment, Food and Rural Affairs risk assessment guidelines note the following definitions for hazard and risk (Defra, 2011):

- **Hazard**: A situation or biological, chemical or physical agent that may lead to harm or cause adverse affects;
- **Risk**: The potential consequence(s) of a hazard combined with their likelihoods/probabilities.
Hazard is therefore the cause and Risk is therefore the probability of effect (likely consequences) leading to adverse or unwanted effects.

As potential consequences (the risk) of a cause (the hazard) can occur for different types of asset, methods for assessment of risk may differ between industries and whether the RA refers to financial decisions, environmental concerns, human health concerns, or damage to a physical structure. For example, Scenario A, in Table 1, would be regarded widely as a simple risk assessment due to a high visual impact and much media coverage. However, a risk assessment for Scenario B is also applicable. In each case the numerical probability of each scenario occurring would be assessed (if possible, given existing data and knowledge) and appropriate measures put in place to ensure the likelihood was minimised.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hazard (cause)</th>
<th>Risk (consequence)</th>
<th>Possible control measure</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Oil spill from tanker ship</td>
<td>Rare seabird population nesting on nearby beach killed by oil</td>
<td>Tanker to take a different route to destination during breeding season</td>
<td>In this scenario, the manmade asset (the oil in the tanker) is a potential hazard to the nesting bird population</td>
</tr>
<tr>
<td>B</td>
<td>Encrusting marine fauna</td>
<td>Corrosion and weakening of ship hull resulting in spillage of oil</td>
<td>Use of antifouling paint to discourage growth of marine life</td>
<td>In this scenario, the environment is the potential hazard to the manmade asset.</td>
</tr>
</tbody>
</table>

The hazard can be categorised as biological, chemical, radiation and/or physical (Calewaert, 2013; Defra, 2011) and can occur at the cell, individual, population, community or ecosystem level (Calewaert, 2013; Fairman et al., 1999). Elliott et al. (2014) created a typology of 13 types of hazard and risk in the marine environment, all of which can be related to or influence offshore marine energy generation (see Appendix 2). The asset that is affected (sometimes referred to as the risk receptor) can vary in size and scale, e.g. cellular changes, human individuals or the wider population, fauna and flora (single species or whole ecosystems), and materials (e.g. impacts on buildings by acid rain, loss or damage of property by a storm surge).

It is important to define a measurable end-point for each asset affected. Different scenarios will have different end-points which may be health related (e.g. mortality), ecology/environmental related (e.g. a permanent habitat change), financial related (e.g. revenue loss) or physical in nature (e.g. property loss/damage) (Elliott et al., 2014). For example, in the oil spill example above (Scenario A in Table 1), the end point could be the complete loss of the breeding colony or it could be the loss of 50% of breeding adults. The methods used in the RA will be dependent on which risks, assets and endpoints are of concern and each RA will be unique, there is no ‘one size fits all’ RA that can be used.
Case Study – Wind Farms in the Dogger Bank (North Sea)

Case Study Location – Dogger Bank.

The coastal waters of the UK, Netherlands, Denmark and Germany already support wind power generation to contribute towards EU renewable energy targets, and the high wind resource coupled with low tidal stresses in the North Sea, mean that the North Sea region is particularly suited to the development of offshore wind power (Ackermann and Söder, 2002). Shared between these countries, the shallow waters and large footprint of the Dogger Bank (Figure 2) make it especially suitable for offshore wind farms and hence it is the area selected as a case study for this exercise.

The Dogger Bank is a shallow, large mixed-sediment bank in the North Sea, overlapping the international waters of the UK, Denmark, the Netherlands and Germany (Figure 2). It is approx. 18 m higher than the surrounding seafloor and is approx. 257 km wide (east-west) and 96 km long (north-south) at the deepest point (approx 36.5 m). The presence of mammalian bones and mineral composition of the sediments suggest the age of the bank to be from the Pleistocene Era, at which point it was exposed. The Dogger Bank is thought to be a large, terminal glacial moraine (Stride, 1959). Mollusc shells recovered are species known to be from shallow water and their presence in the surficial sediments of Dogger Bank indicate that the sea level was once 20 m lower than present, and further indicates that no important sedimentation has occurred on Dogger Bank since the Lower Holocene Era (Veenstra, 1965). The Dogger Bank is a productive fishing ground and its name comes from an old Dutch word ‘dogger’, a type of fishing vessel.

The UK part of Dogger Bank (Figure 2) was submitted by the UK Joint Nature Conservation Committee (JNCC) to the European Commission (EC) as a candidate Special Area of Conservation (cSAC) on 26 August 2011. Following approval by the EC, it has been designated as a Site of Community Importance (SCI) and it now remains a cSAC and SCI whilst awaiting review by UK Government to become a fully designated SAC (JNCC, undated). Ecologically, Dogger Bank supports a benthic community typical of sandy and mixed sediments, including polychaetes, amphipods and small bivalve molluscs. Epibenthic species include hermit crabs, flatfish and echinoderms. Sand eels are abundant on the edges of the Bank providing a food resource for seabirds, cetaceans and commercial fish species, such as cod. The Dogger Bank region is an important location for the North Sea harbour porpoise population and both grey and common seals occur in the region (JNCC, undated). Dogger Bank is a cross boundary Natura 2000 site and The Netherlands and Germany also consider their parts of the Dogger Bank as a SAC, however Denmark does not (Forewind, 2013; Natura2000, undated).

Figure 2   Dogger Bank, North Sea (source: VECTORS).
The part of the Bank within UK waters has been agreed to be developed as part of the Round Three wind farm development, by Forewind, a consortium of RWE, SSE, Statkraft and Statoil. The target is to install 9GW of energy capacity by 2020 to help meet UK Government targets of 20% of energy from renewable sources by 2020. This 9GW figure equates to around 10% of the UK’s estimated energy requirements and is likely to be the world’s largest offshore wind project when fully developed (RWE, undated).

Dogger Bank Creyke Beck (previously known as Dogger Bank Offshore Wind Farm) is the first stage of the Forewind offshore wind energy development in this area (Zone 3, Round 3). It will comprise two wind farms, each with an installed capacity of up to 1.2GW. These wind farms will connect to the UK national grid at Creyke Beck (Cottingham, East Riding of Yorkshire) (Forewind, 2013). Transboundary consultations with regards to the Creyke Beck wind farm occurred between Forewind and representatives from Belgium, Denmark, France, the Netherlands, Germany, Norway and Sweden. The main concerns of users of the Dogger Bank were for the potential transboundary concerns arising from: navigation/shipping (especially when considering cumulative effects from other wind farms e.g. Anglia, Hornsea and Teeside), commercial fishing, barrier effects for sea birds and mammals, cumulative effects of Dogger Bank and the proposed Teesside site on barrier effects to migrating seabirds between Scotland and the Netherlands. However these concerns were assessed to be of only negligible to minor adverse effect (Forewind, 2013).

**Dogger Bank RA case study: Methodology**

There are many RA methods and the accompanying terminology in current literature is often very confusing, especially regarding meanings of hazard and risk (often these two terms are confused and used interchangeably). For ease and clarity of understanding, this report will use the Bow Tie approach (Figure 3) and the following definitions which have been devised from existing definitions (Box 1):
**Box 1  Definitions used throughout the Dogger Bank risk assessment case study.**

*Hazard:* this is an event which has the potential to cause a loss of control of something in the system.

*Cause:* this is the agent that might lead to the hazard event occurring.

*Consequence:* this is the direct or indirect result of the hazard event occurring.

*Prevention measure:* this is a measure put in place with the aim of preventing the hazard event occurring; it may be a physical measure e.g. requiring appropriate technologies, or a non physical measure e.g. a legislative or economic instrument.

*Mitigation measure:* this is a measure put in place/activated should the hazard event occur, despite the preventative measures being there; mitigation measures cannot prevent a consequence but aim to minimise the extent of any consequence (loss/damage/disruption etc) caused by the hazard event.

*Barrier:* collectively, prevention and mitigation measures are called barriers.

*Risk:* this is the probability or likelihood that (1) the hazard will occur due to a particular cause, and, (2) the probability that the consequence will occur. Risk is ideally calculated for both before and after control measures have been put in place given that these measures should lower the risk. Risk calculations provide a quantitative assessment of risk, however they are not always possible to determine conclusively and will sometimes depend on expert opinion and judgement.

*Compensation:* in cases where all preventative measures fail and mitigation is not possible (or also fails) then compensation of the users (economic), of the resource or of the habitat may need to be considered (see Elliott et al., 2007).

A Bow Tie is a diagram visualising the scenario being considered and shaped somewhat like a bow-tie, the diagram creates a clear differentiation between preventative and mitigation measures – effectively ways to prevent an event from happening, and if it does, ways to mitigate any effects (Figure 3). The power of a Bow Tie is that it summarises numerous risk scenarios, in a single, easy to understand, simple and visual indication of a single or set of risks that would be much more difficult to explain otherwise. Originally designed for the hazards and risks associated with Health and Safety practices, the wide scope and capabilities of Bow Tie analysis mean that it can be adapted for several purposes including reviews of legislation and ecological assessments and investigations. It can be expanded to include quantitative information, and hence has the potential to become a predictive model, as well as incorporating factors that may affect the adequacy of any control measures.
Figure 3 Simplified representation of the Bow Tie approach to risk assessment and management. Any cause can lead to the hazard event in the centre of the diagram, which can result in any of the consequences.

By adapting the steps outlined by Fairman et al (1999), Brandsaeter (2002) and Calewaert (2013) and combining this with the cause—hazard—consequence Bow Tie approach, we formulated a six step method for our RA (Table 2). In order to perform this six step analysis, firstly, to assess both the hazards of the activity in question (wind farms) on the marine environment, and, secondly, the hazards of the marine environment on the wind farm, two comprehensive tables were created (Table 3, Table 4). These tables list the possible effects that the wind farm and the environment may have on each other. The way in which these are categorised in terms of being a cause or a consequence will depend on the top event for the Bow Tie, i.e. the event to be avoided and for which the risk assessment is to be performed. This is then followed by assembling the risk assessment and associated preventative and mitigation measures. Hence, the potential effects or impacts of wind farms were compiled in two veins:

1) the impacts that the surrounding environment may have on the wind farm;
2) the impacts that wind farms may have on the surrounding environment.
The impacts in vein 2 were derived from examining documents relating to current and planned wind farms as well as from Elliott (2002) (Figure 4). For example, all Environmental Statements for offshore wind installations include site-specific information on both the biotic components (communities, population dynamics, distribution, abundance) and the abiotic components of the environment (habitat types and characteristics, physical and chemical features, morphology, waves, currents, temperature, salinity). These data give a context against which pressures and impacts can be measured.

The 2004 OSPAR investigation into the possible impacts of a wind farm on the environment (Table 5) is given here as it summarises a range of potential impacts which have been categorised in a different way, by indicating different aspects of the environment and users of the environment.

**Table 2** Six steps to performing an Environmental Risk Assessment and steps that can be included to make the assessment more quantitative (expanded and adapted from basic procedures described in Fairman et al 1999; Brandsaeter, 2002; Calewaert, 2013).

<table>
<thead>
<tr>
<th>Six steps of an ERA and associated key-questions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Problem Formulation</td>
<td>What needs to be assessed?</td>
</tr>
<tr>
<td>2. Hazard Identification</td>
<td>What can go wrong? (What are the hazards?)</td>
</tr>
<tr>
<td>3. Cause Identification</td>
<td>What can lead to the hazard occurring? (What causes the hazard?) Quantitative: How often or how likely is it that these causes will occur?</td>
</tr>
<tr>
<td>4. Exposure Assessment (This is a quantitative step that is not necessary but adds value to the risk assessment)</td>
<td>Quantitative: How does the hazard reach the receptor and/or the receiving environment? At what intensity? How long for and/or how frequently does the hazard reach or affect the receptor/receiving environment? Quantitative: How likely is it that the receptors/receiving environment will be exposed to the hazard?</td>
</tr>
<tr>
<td>5. Consequence or Effect Identification</td>
<td>What are the consequences of the hazard if it occurs?</td>
</tr>
<tr>
<td>6. Risk Characterisation and Estimation for Consequences</td>
<td>What are the risks (quantitative or qualitative measure)? Quantitative: What is the probability of the consequence happening? This can be estimated for both before and after preventative and mitigation measures are put in place.</td>
</tr>
</tbody>
</table>
Table 3  Possible effects from the marine environment on the wind farm

<table>
<thead>
<tr>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
</tr>
<tr>
<td>Encrusting marine fauna</td>
</tr>
<tr>
<td>Biofouling</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Chemical</td>
</tr>
<tr>
<td>Corrosive nature of sea water</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Physical</td>
</tr>
<tr>
<td>Waves</td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Storm surges</td>
</tr>
<tr>
<td>Storm events</td>
</tr>
<tr>
<td>Earthquakes</td>
</tr>
<tr>
<td>Climate change</td>
</tr>
<tr>
<td>When the wind is too strong the turbine has to be shut down or damage can occur</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 4  Possible effects from the wind farm on the marine environment

<table>
<thead>
<tr>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
</tr>
<tr>
<td>Acting as a stepping stone for non indigenous species*</td>
</tr>
<tr>
<td>Acting as a stepping stone for invasive non-indigenous species*</td>
</tr>
<tr>
<td>Species changes (implications for fishing industry?)*</td>
</tr>
<tr>
<td>Community changes*</td>
</tr>
<tr>
<td>Bird migrations*</td>
</tr>
<tr>
<td>Bird collisions</td>
</tr>
<tr>
<td>Light a night from warning lights etc (bats / birds / insects / aquatic spp)</td>
</tr>
<tr>
<td>Positives e.g. habitat creation / artificial reefs*</td>
</tr>
<tr>
<td>Chemical</td>
</tr>
<tr>
<td>Chemical leaks</td>
</tr>
<tr>
<td>Physical</td>
</tr>
<tr>
<td>Habitat changes from introducing a different substratum</td>
</tr>
<tr>
<td>Noise during construction / operation / decommissioning*</td>
</tr>
<tr>
<td>Sediment changes of substratum*</td>
</tr>
<tr>
<td>Sediment changes – suspended sediment loads (especially during construction and decommissioning)*</td>
</tr>
<tr>
<td>Removal of energy from the system (wind/water)*</td>
</tr>
<tr>
<td>Seascape alteration / public perceptions</td>
</tr>
<tr>
<td>Environmental goods/services</td>
</tr>
<tr>
<td>Light at night from warning lights</td>
</tr>
<tr>
<td>Impacts on weather and weather systems*</td>
</tr>
<tr>
<td>Electromagnetic fields (EMFs) &gt; migrations changes, species changes*</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>N/A</td>
</tr>
</tbody>
</table>

* possibility for cumulative effects
Figure 4 Environmental consequences of offshore wind power generation during exploration, construction and operation (Elliott, 2002).
<table>
<thead>
<tr>
<th>Issue</th>
<th>Source of Potential Impacts</th>
<th>Examples of Potential Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birds</td>
<td>turbines, mainly rotor blades and wakes light emission</td>
<td>bird collision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>attraction of birds due to illumination by navigational lights and subsequent increase in the risk of collision</td>
</tr>
<tr>
<td></td>
<td>wind farm as a whole</td>
<td>temporary or permanent habitat loss or change, including exclusion of habitat, e.g. sandbanks, water surface/water body due to disturbance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fragmentation of feeding, breeding and roosting areas, as well as migratory routes due to barrier effect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>change of food species availability</td>
</tr>
<tr>
<td></td>
<td>boat traffic during construction and maintenance</td>
<td>stress and reduction of biological fitness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>temporary or permanent exclusion from habitat</td>
</tr>
<tr>
<td></td>
<td>electric cable to shore – increase of temperature in sediments during operation</td>
<td>increased risk of botulism in coastal areas (eulittoral) resulting in an increased death rate for wading birds and water birds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bats</td>
<td>turbines mainly rotor blades and wakes</td>
<td>collision and barrier effects</td>
</tr>
<tr>
<td>Marine mammals</td>
<td>shadow from rotor blades</td>
<td>habitat loss due to avoidance</td>
</tr>
<tr>
<td></td>
<td>emission of sound and vibration into the water body</td>
<td>fragmentation of migratory routes and of sites for foraging and reproduction</td>
</tr>
<tr>
<td></td>
<td>construction noise (including pile driving)</td>
<td>induced permanent or temporary threshold shift in hearing (PTS/TTS), reduced perception of biologically significant sounds (masking)</td>
</tr>
<tr>
<td></td>
<td>electric cables (see below) -</td>
<td>disturbance of small- and large-scale orientation</td>
</tr>
<tr>
<td></td>
<td>boat traffic during construction and maintenance</td>
<td>changed behaviour, stress</td>
</tr>
<tr>
<td>Fish</td>
<td>electric cable within the wind farm and to shore – artificial electromagnetic fields emitted during operation, in particular from monopolar direct current cables</td>
<td>disturbance of small- and large-scale orientation (especially migratory species)</td>
</tr>
<tr>
<td></td>
<td>emission of sound and vibration into the water body</td>
<td>impediment of foraging activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>physical barrier</td>
</tr>
<tr>
<td></td>
<td>clouding and sedimentation during construction</td>
<td>habitat loss as fish may leave area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>disturbance of behaviour and stress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>damage to fish eggs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>damage and or disturbance to spawning grounds</td>
</tr>
<tr>
<td>Issue</td>
<td>Source of Potential Impacts</td>
<td>Examples of Potential Impacts</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>introduction of hard substratum</td>
<td>alteration of food species availability and abundance, which in turn may alter community composition and abundance of fish</td>
<td></td>
</tr>
<tr>
<td>construction noise (including pile driving)</td>
<td>induced permanent or temporary threshold shift in hearing (PTS/TTS), reduced perception of biologically significant sounds (masking)</td>
<td></td>
</tr>
<tr>
<td>cable laying</td>
<td>disturbance of intertidal habitats</td>
<td></td>
</tr>
<tr>
<td>Zoobenthos</td>
<td>local destruction and sediment plumes during the construction/removal of foundations Permanent covering of the sea floor</td>
<td>temporary and permanent habitat loss Alteration in benthic community composition</td>
</tr>
<tr>
<td>Zoobenthos</td>
<td>Introduction of artificial hard substrata Changes in hydrodynamics</td>
<td>Indirect habitat loss through small-scale changes in sediment structure and around the turbine and changes of large-scale sediment dynamics</td>
</tr>
<tr>
<td>Zoobenthos</td>
<td>Electric cable within the wind farm and to shore – increase of temperature in sediments during operation</td>
<td>Alteration in endobenthic community including colonisation by alien species Increased degradation of the organic content resulting in a release of heavy metals (depending on the total organic matter content and metal content of the sediment)</td>
</tr>
<tr>
<td>Macrophytes</td>
<td>Local destruction and sediment plumes during the construction of foundations Permanent covering of the sea floor</td>
<td>Temporary and permanent habitat loss</td>
</tr>
<tr>
<td>Macrophytes</td>
<td>Change of current dynamics and sediment conditions Introduction of an artificial hard substrate</td>
<td>Habitat loss Alteration in the plant community composition</td>
</tr>
<tr>
<td>Hydrodynamics and Morphodynamics</td>
<td>Construction and presence of foundations and cables</td>
<td>change of sediment dynamics, for example slowing down of natural erosion and sedimentation processes (at the site and adjacent coastlines) reduction in wave energy (shadow effects) from different sized arrays and how/if this influences sediment inputs and exchanges beach faces and flood defences</td>
</tr>
<tr>
<td>Landscape</td>
<td>tall structures visible from afar lighting</td>
<td>intrusion on the typically flat and featureless sea and “industrialisation” of this natural landscape alteration of the scenic landscape – especially at night</td>
</tr>
<tr>
<td>Issue</td>
<td>Source of Potential Impacts</td>
<td>Examples of Potential Impacts</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------</td>
</tr>
<tr>
<td>Navigation</td>
<td>danger of collisions between vessels and wind turbines (including restriction/constriction of shipping routes)</td>
<td>pollution through oil spills or chemical spills</td>
</tr>
<tr>
<td></td>
<td></td>
<td>impact on socio-economic operations</td>
</tr>
<tr>
<td>Emergency operations</td>
<td>obstacles due to the presence of static structures</td>
<td>impact on emergency operations</td>
</tr>
<tr>
<td>Other users</td>
<td>exclusion of other users from the area disturbance of the natural landscape</td>
<td>socio-economic losses e.g. for fisheries and tourism</td>
</tr>
</tbody>
</table>

It is of note that for any anthropogenic installation in the marine environment, thorough environmental impact assessments and health and safety (H&S) based risk assessments (RA) must be undertaken by the company constructing the installation. It is axiomatic that the developer has to demonstrate no effect on the environment whereas the regulator does not have to prove an effect. Hence, although the tables above list as many potential impacts as possible, the RA in this report does not take into account the types of hazard and risk that are already covered H&S RAs; for example, personnel working at height in windy conditions. This RA takes a wide view and hence not all of the above potential impacts appear in this RA.

**Possible larger scale or cumulative effects of wind farms**

In general, there is a poor understanding of the cumulative effects with regard to wind farms (either terrestrial or offshore). This may be largely due to there being relatively few large scale wind farms operating and none are what may be considered as multiple large scale wind farms in the same area. Most available studies consider impacts that may occur to shipping and navigation, migration routes of birds, as well as effects from sound on marine mammals. There are also reports that large scale wind farms may affect weather patterns (see below).

**Wind farms affecting birds and mammals**

In an analysis of several EIAs and Appropriate Assessments (for the EU Habitats Directive) for UK Round 2 North Sea wind farms, Boon (2012), found that the detour made by migrating birds to avoid a single large offshore wind farm was negligible compared to the whole migration distance. However, the cumulative impact of offshore wind farms on migrating birds (impacts = collisions and barrier effects) and seabirds (impacts = collisions and habitat loss) may become important in the future when tens of GW of offshore wind farms will be installed (Boon, 2012). A modelling study performed at the population level for several seabird species in the Netherlands (Poot et al., 2011), predicted that for a single wind farm the effects on the population are much less than those at which serious negative impacts occur. Furthermore, for most species even a tenfold extrapolation of the effects are still within safe limits, except for the herring gull and Bewick’s swan. The population of herring gulls was already declining, and the presence of wind farms was expected to extend this decline (Poot et al., 2011). In addition the possible loss of the Dutch coastal corridor for pregnant seals as well as potential underwater sound effects also possibly remove habitat for seals and porpoises for foraging, mating, resting etc (Boon, 2012). Although wind energy is generally considered environmentally benign (Wilson et al., 2010), poorly sited or designed wind farms may have negative impacts on the environment. The EU Wild Birds Directive and the Habitats Directive (see Appendix 1) together form a legal framework for protecting the
European natural environment and its wildlife. Most negative effects can be removed or minimised by avoiding sites with sensitive habitats, and good site location will also help developers avoid costly investments in inappropriate sites (Drewitt and Langston, 2006; Hansen, 2011). Marine spatial planning at the regional level hence will allow successful wind energy development from a nature conservation point of view.

**Wind farms affecting the weather**
At present, offshore wind farms do not exist on a large spatial scale, although this is highly likely to change in the near future. At the local/small scale both terrestrial (Roy and Traiteur, 2010) and offshore (Christiansen and Hasager, 2005; Emeis, 2010) wind farms are considered to affect local meteorology. This raises the question over whether wind farms with a large spatial footprint, or several smaller wind farms covering the same area, may affect regional or global environmental systems. This would happen by the farms effectively combining to affect weather patterns by vertical mixing of energy and heat in atmospheric layers that can affect local temperatures, and possibly change evaporation patterns (Baidya Roy et al., 2004; Keith et al., 2004). A wind farm can absorb energy as well as create turbulence (Baidya Roy et al., 2004) and large-scale use of wind power may alter local and regional climate conditions by extracting kinetic energy and altering turbulent transport in the atmospheric boundary layer (Keith et al., 2004). Climate modelling suggests that very large wind power developments can produce a notable climatic change at continental scales, but that although large-scale effects are observed, wind power has a negligible effect on global-mean surface temperature (Keith et al., 2004). A 25-year data set (based on wind farms with ≈20 turbines) showed a significant effect of terrestrial wind farms on near-surface temperatures, confirming that previously predicted effects had occurred, for example in the North American Great Plains region. Hence those constructing wind farms should consider low-turbulence turbines or use the results to help find the most suitable sites. The main impact of the terrestrial wind farms was in raising surface temperatures at night and lowering them during the day - which was thought to benefit agriculture by decreasing frost damage and extending the growing season. It was concluded that local effects will be more marked in much larger terrestrial windfarms (Roy and Traiteur, 2010).

Recent satellite observations demonstrated that several large terrestrial wind farms in the USA increased local night time minimum surface temperatures compared to surrounding areas due to increased turbulence in a normally stable nocturnal boundary layer causing warm air to mix lower down hence raising the surface temperature (Zhou et al., 2012). Large scale wind farms are also expected to affect local precipitation (Fiedler and Bukovsky, 2011), cloud formation (Emeis, 2010) (Figure 5), and are expected to impact on gravity wave generation with a “choking” effect causing winds at a turbine to suddenly reduce (Smith, 2009). With the exception of Christiansen and Hasager (2005) and Emeis (2010), these studies are focused on terrestrial wind power developments and whether similar impacts will be caused by offshore developments is unknown but must not be discounted.

The above potential changes to weather and climate may be outweighed by the positive climatic effects of reducing fossil fuel consumption and therefore CO₂ outputs. Furthermore turbine designs may be modified to increase the atmospheric efficiency, and considerably reduce the generation of turbulence (Baidya Roy et al., 2004; Keith et al., 2004; Roy and Traiteur, 2010). Additional mitigation of any impact might be achieved by siting wind farms such that their effects partially cancel each other and by tailoring the interaction of turbines with the local topography to minimize the added drag (Keith et al., 2004).
Increased navigational issues
A wind farm is a large static object in a normally clear area and so new navigational risks may result from new offshore wind farms. Such risks may be compounded when several wind farms operate in large parts of a body of water, for example the North Sea. These risks can be divided into four categories: a) risk of a ship colliding with or contacting a wind turbine or wind farm structure; b) risk of ship to ship collision resulting from change in navigation to avoid the wind farm area; c) grounding risks; d) possible secondary risks resulting from effects of the wind farm on, for example, radar operations. Formal Safety Assessment is a structured and systematic RA and cost-benefit guideline developed by the International Maritime Organisation of the United Nations, aimed at enhancing maritime safety, protecting life, health, the marine environment and property (Hansen, 2011). However this is not a legal requirement and it is the decision of individual countries to adopt these guidelines into their national legal frameworks.
Dogger Bank RA, case study: Bow Ties

Following the identification of potential impacts, Bow Tie XP/XL software (CGE Risk Ltd) was used to create a diagram to visualise and order each hazard and associated causes and effects, as well as both preventative and mitigation measures.

Basic Scheme (vein 1) – the way in which the effects of climate change can potentially impact on the wind farm and its operation:

This scheme assesses top level events linked to climate change, that have the potential to cause the loss of the wind resource, or a decrease in the ability to produce wind energy in the Dogger Bank, North Sea. The following series of figures explain the concept of Bow Tie analysis in the context of this case study focusing on the way in which the effects of climate change can potentially impact on the wind farm and its operation.

The Bow Tie centres around a central hazard, in this case that is loss of the wind resource, or a decrease in the ability to produce wind energy, on the Dogger Bank as a result of climate change (Figure 6). The hazard is depicted inside the yellow and black hatched box, and the loss of control of the system – the point at which wind energy is no longer produced – is depicted inside the red circle.

From this starting point, 13 causes and 6 consequences were identified (Figure 7). Causes (red, left hand side) are events that may cause the central event to happen and consequences (blue, right hand side) are effects that may occur as a result of the hazard occurring. These are:
Causes
- Altered wind currents, patterns and baseflows
- Increased frequency and intensity of cyclones/hurricanes
- Changed icing conditions and snow falls
- Increased frequency and intensity of storm surges
- Rise in sea level changing airflow patterns from laminar to turbulent
- Rise in sea level causing more stress to the structure
- Altered sea current patterns and baseflows
- Stronger/more frequent unusual hydrodynamic events
- Increase in biofouling
- Inflow of alien species threatens structural integrity/stability
- Changes in species migration patterns
- Increased demand for cooling or heating. Change in public policy towards renewables
- Changes in shipping lanes and increased risk of accidents

Any of these causes may result in the loss or reduction of the wind resource or the ability to produce sufficient wind energy. For example, altered wind patterns may mean severely stronger winds, which means that wind farms cannot operate. It may also mean that winds decrease such that the wind resource is not sufficient for production. Climate change may cause an inflow of alien species through new/more species using warmer waters in the North Sea. These may contribute to biofouling which adds stress to the wind farm structure.

Consequences
- Physical equipment damage
- Electrical system failures
- Infrastructure damage
- Impact on structural integrity or stability
- New ecosystem impacts
- Increased reliance on external or internal sources of energy e.g. nuclear or imported gas

Any of these consequences may occur as a result of the hazard occurring. For example, the loss of the wind energy resource may result in physical equipment damage, e.g. storms causing broken blades. The loss of wind energy may also cause an increased reliance on alternative energies, for example nuclear or gas.

Once causes and consequences were established, ways of preventing the hazard from occurring were identified (Figure 8) (multicoloured, left hand side) and ways of mitigating the extent of the consequences should the hazard occur were identified (multicoloured, right hand side). Escalation factors (yellow) were provided to explain instances when some of the prevention or mitigation measures may be weakened or fail. The complete diagram (Figure 8) is broken down in the following pages (Figure 9 to Figure 13) for ease of reading.
Figure 7  Basic Scheme (vein 1). Showing causes (blue) and consequences (red)
Figure 8  Bow Tie scheme showing the prevention measures (to the left of the central hazard) and the mitigation measures (to the right of the central hazard) and escalation factors (yellow) that can cause a prevention or mitigation measure to fail. Zoomed in views follow.
Figure 9  Zoomed-in view of the top section of the diagram. Showing the prevention measures that are specific to that cause, that reduce the likelihood of the central hazard happening, and escalation factors (yellow) that can cause the prevention measure to fail or be less effective.
Figure 10  Zoomed-in view of the upper centre of the diagram. On the left hand side are causes (blue) and prevention measures (multicoloured) that are specific to that cause that reduce the likelihood of the central hazard happening. On the right hand side are consequences (red) and mitigation measures (multicoloured) that are specific to that cause that reduce the magnitude of the consequence. Escalation factors (yellow) are shown that can cause the prevention or mitigation measures to fail or be less effective.
Figure 11  Zoomed-in view of the centre of the diagram. On the left hand side are causes (blue) and prevention measures (multicoloured) that are specific to that cause that reduce the likelihood of the central hazard happening. On the right hand side are consequences (red) and mitigation measures (multicoloured) that are specific to that cause that reduce the magnitude of the consequence. Escalation factors (yellow) are shown that can cause the prevention or mitigation measures to fail or be less effective.
Figure 12  Zoomed-in view of lower centre of the diagram. On the left hand side are causes (blue) and prevention measures (multicoloured) that are specific to that cause that reduce the likelihood of the central hazard happening. On the right hand side are consequences (red) and mitigation measures (multicoloured) that are specific to that cause that reduce the magnitude of the consequence. Escalation factors (yellow) are shown that can cause the prevention or mitigation measure to fail or be less effective.
Figure 13  Zoomed-in view of the bottom section of the diagram. Showing the prevention measures (multicoloured) that are specific to that cause (blue), that reduce the likelihood of the central hazard happening. Escalation factors (yellow) that can cause the prevention measure to fail or be less effective are also shown.
Focused example of causes and consequences (effects of the environment on the wind farm)

Analysis of three of the potential causes and three of the potential consequences (Figure 14) to illustrate the Bow Tie approach.

If climate change results in increased occurrences or intensity of hurricanes, this could threaten wind power resources and the ability to produce sufficient energy. The consequences of these storms and the reduction or loss of production could be (1) physical equipment damage, (2) damage to the infrastructure, (3) potential new ecosystem impacts.

To help prevent the loss of or a decrease in the ability to produce wind energy, certain barriers can be put into place: (1) in anticipation of more severe weather, which would put a stress on the structure of the windmill, installations could be designed and built with stronger materials; (2) enhanced local weather forecasting would enable operators to predict when dangerous wind speeds would occur, which would lead to (3) shutdown procedures to help protect moving parts during hurricane and other severe weather events.

If climate change results in increased demand for cooling (e.g. if warmer weather was more frequent) or heating (should winters become colder), this could mean that there is a reduction in the ability to produce sufficient energy to meet demands, or a loss of energy production if structures cannot cope with more extreme weather. Consequences could again be: (1) physical equipment damage, (2) damage to the infrastructure, (3) potential new ecosystem impacts.

Barriers/control measures that could be put in place to help ensure these consequences do not happen include: (1) upscaling (re-powering) existing wind farms with larger capacity windmills to cope with more demand, and (2) relaxing existing legislation to allow the consenting process for new wind farm projects to proceed with more ease.

Changes in shipping activity and the re-location of shipping lanes may also occur as a result of climate change. This could occur through changing sea levels altering the safest routes or because the location of ports may have to change. Furthermore, more wind farms and other renewable energy installations e.g. wave and tidal, will mean greater demands on space and ships may be forced to navigate around such new obstacles. New wind farms may not be consented, which could result in the reduction of wind energy production, or more competing demands on space may mean the potential for collisions between ships and turbines, again threatening energy production.

Barriers that could be put in place to help prevent this loss/reduction include: (1) navigational technology on board ships and other water craft; (2) marine spatial planning, and (3) separation of activities to ensure less chance of accidents.

Prevention measures can be categorised by their effectiveness, the type of measure, e.g. hardware, operating procedure, defence measure, etc. The diagram can be further extended to be made quantitative by assigning a numerical value to such factors where known, to determine how critical they are to the system.
The prevention measures described above all aim to reduce the likelihood of the central event/hazard. Therefore they should all help to reduce the probability that there will be the loss of or reduction in the ability to produce wind energy in the North Sea. However, should this still occur, the right hand side of the Bow Tie diagram indicates mitigation measures (Figure 15).

The extent of physical equipment damage can be mitigated by: (1) having access to back up spare parts, (2) shutdown procedures, (3) increasing servicing and maintenance.

Infrastructure damage can be mitigated by: (1) having access to alternative cable routes, (2) being connected to the proposed EU supergrid, (3) increasing servicing and maintenance.

New ecosystem impacts can be prevented and mitigated through existing EU Directives, which serve as legislative tools to which all Member States must adhere, to prevent ecological deterioration and harm. As long as these Directives are being followed, ecosystem impacts should be negligible or tolerated.

Some of these prevention and mitigation measures have escalation factors attached (yellow box). For example, the ability to enable effective shutdown procedures in advance of a storm event are dependent on the accuracy of local weather forecasting. Poor forecasting could cause the shutdown procedures barrier to fail, which would produce greater damage. The ability to join the proposed Supergrid depends on agreement and cooperation by Member States and having the appropriate technology available.
Figure 15 Fully expanded view of the Focused Example, showing (right hand side) examples of consequences, mitigation measures and escalation factors.
The Bow Tie analysis is not just for Risk Assessment, but for a complete Risk Management of a system. The working files can detail the hazards of concern, with descriptions and explanations of the hazard, consequences and barriers (Figure 16). It is also possible to include clickable links to web pages, reports and peer reviewed articles (e.g. blue text in the highlighted box for Birds Directive).
Basic Scheme (vein 2) – how the operation of the wind farm may affect the environment.

This scheme investigates the very top level events linked to the construction and operation of wind farms in the North Sea, that have the potential to affect the environment by causing an unwanted change in terms of Good Environmental Status (GEnS) as described by the Marine Strategy Framework Directive (MSFD) (e.g. Borja et al., 2013). The following series of figures explain the concept of Bow Tie analysis diagram in the context of this case study, in essence indicating the way in which a wind farm can affect the environment.

The process by which the development of offshore wind energy can lead to potential changes to GEnS is shown in Figure 17. There are many reasons which may mean that need for wind energy is increased, for instance, population increase, changing demand for electricity, exhaustion of fossil fuel resources etc. The installation of an offshore wind farm due to these reasons will then lead to a series of potential changes to the environment. This cause—effect has been described in Figure 4 (page 19) and is covered by the red hatched box in Figure 17. These changes could in turn lead to various environmental changes (as described by Figure 4), which if of a sufficient magnitude, could result in a failure to meet GEnS targets. Once GEnS is failed, there will be various consequences, each which have a range of mitigation measures to reduce their impact. This process, including ways to prevent and mitigate for a failure of GEnS (the blue hatched box) is what has been described by the following Bow Tie diagram.

The Bow Tie centres around a hazard, which in this case has been categorised as the area deteriorating and therefore failing to meet the requirements of the MSFD in terms of the GEnS descriptors (Figure 18). The hazard is depicted inside the yellow and black hatched box, and the loss of control of the system – the failure to meet MSFD requirements – is depicted inside the red circle.
This Bow Tie is based on and operates in terms of the descriptors of GEnS as defined by the MSFD, to describe how the wind farm can affect the environment. From this starting point, 11 causes (red, left hand side) and 9 consequences (blue, right hand side) were identified (Figure 19).

The causes in this diagram are based on the descriptors of GEnS from the MSFD. GEnS is defined under Article 3 of the MSFD as 'The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive.'

GEnS means that the different uses made of the marine resources are conducted at a sustainable level, ensuring their continuity for future generations. In addition, GEnS means that:

a) ecosystems, including their hydro-morphological (i.e. the structure and evolution of the water resources), physical and chemical conditions, are fully functioning and resilient to human-induced environmental change;

b) the decline of biodiversity caused by human activities is prevented and biodiversity is protected;

c) human activities introducing substances and energy into the marine environment do not cause pollution effects; noise from human activities is compatible with the marine environment and its ecosystems.

**MSFD descriptors**

Descriptor 1: Biological diversity
Descriptor 2: Non-indigenous species
Descriptor 3: Population of commercial fish / shell fish
Descriptor 4: Elements of marine food webs
Descriptor 5: Eutrophication (note: eutrophication is negligible for offshore wind power)
Descriptor 6: Sea floor integrity
Descriptor 7: Alteration of hydrographical conditions
Descriptor 8: Contaminants
Descriptor 9: Contaminants in fish and seafood for human consumption
Descriptor 10: Marine litter
Descriptor 11: Introduction of energy, including underwater noise

Annex I of the MSFD sets out eleven qualitative descriptors which describe what the environment will look like when GEnS has been achieved. The aim of this is to assist Member States to interpret what GEnS means in practice:

Descriptor 1: Biodiversity is maintained
Descriptor 2: Non-indigenous species do not adversely alter the ecosystem
Descriptor 3: The population of commercial fish species is healthy
Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
Descriptor 5: Eutrophication is minimised *(note: eutrophication is not applicable for offshore wind power)*
Descriptor 6: The sea floor integrity ensures functioning of the ecosystem
Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
Descriptor 8: Concentrations of contaminants give no effects
Descriptor 9: Contaminants in seafood are below safe levels
Descriptor 10: Marine litter does not cause harm
Descriptor 11: Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Note that Descriptor 5 is not applicable for offshore wind power and has not been included in the following Bow Tie diagram. Descriptors 8 and 9 are considered as negligible and have been included only for completeness.

These above descriptors are criteria by which a loss of GEnS can be measured. Therefore, by using these in association with the information in Figure 4 (see page 19), the causes for this Bow Tie diagram have been formulated as:

**Causes**

- Changes to biodiversity caused by seabed disturbance, scaring away of mammals, damage to bird migrations, etc;
- Increase of habitat diversity allowing non-indigenous species to become established, etc;
- Loss of habitats, e.g. feeding areas, spawning areas etc, for commercial fish/shellfish;
- Changes to populations of predators and prey alters marine food webs;
- Sea floor integrity altered by changes to seabed communities, smothering, erosion, scouring, etc;
- Hydrographical conditions changed by wind farm causing changes to currents, impediments to flow;
- Increased contaminants (e.g. from visiting service vessels) cause harm
- Contaminants in the fish and seafood for human consumption exceed safe levels
- Marine litter increases through input of materials to the system;
- Noise and vibration introduced causing disturbance to marine mammals and fish;
- Electromagnetic fields from increased cabling causes disturbance to marine mammals, elasmobranchs and turtles.
Pressures caused by the construction, operation, or decommissioning of a wind farm could result in any of these causes, which in turn could result in the deterioration of the area and a failure to meet the requirements of the MSFD GEnS. For example, the introduction of a wind farm will alter local habitat diversity through processes such as adding a hard substratum to a normally sandy area. This change may allow for non-indigenous species to become established (see GEnS descriptor 2). Hence the wind farm may act as a ‘stepping stone’ that allows a non-native species to gain access to an otherwise inaccessible area, facilitating their spread and distribution. Such events could lead to the Member State(s) responsible for the wind farm failing to maintain the area in GEnS as required by the MSFD. The process of developing a wind farm could mean that hydrographical conditions are altered (see descriptor 7) through the wind farm changing currents, scouring the bed or impeding flows. This may mean that there is a failure to meet GEnS targets in terms of maintaining hydrography. In turn the following consequences may occur:

- Permanent species distribution changes (range/pattern/area)
- Permanent changes to population size (abundance/biomass)
- Permanent changes to population condition (age structure, fecundity etc)
- Permanent community change e.g. establishment of alien invasive species
- Permanent changes to habitat distribution (range or pattern)
- Permanent changes to habitat extent (area or volume)
- Permanent changes to habitat condition (species composition or abundance/biomass, or physical chemical conditions)
- Permanent ecosystem structure changes (composition and proportion of components)
- Member State placed in infraction (legal) proceedings for breach of GEnS conditions, which leads to financial penalties for the Member State

Any of these consequences may occur as a result of the hazard occurring. For example, failure to meet MSFD GEnS requirements will be manifest as permanent changes to species distributions or the entire ecosystem. It may also mean that the responsible Member State faces infraction (legal) proceedings through failure to meet the Directive.

Once causes and consequences were established for the MSFD Bow Tie (Figure 22), ways of preventing the unwanted change to GEnS were identified (multicoloured, left hand side), and ways identified for mitigating the consequences should GEnS targets fail (multicoloured, right hand side). The main way of maintaining GEnS is to adhere to various EU directives (the preventative measures) and as long as the Directives are followed appropriately, GEnS should be preserved. Although there are many Directives, principally the ones of relevance are the Habitats & Species, Wild Birds, Water Framework (within the near-shore area), Environmental Impact Assessment, and Strategic Environmental Assessment. Each Member State has its own enabling regulations that put these Directives into practice, however they have not been listed in this analysis in order to make the Bow Tie diagram less-complex. Escalation factors (yellow) are provided to explain the occasions when some of the prevention or mitigation measures may be weakened or fail. The complete diagram in Figure 22 is broken down in the following pages (Figure 23 to Figure 26) for ease of reading.
Figure 19 Basic Scheme (vein 2) based on the indicators of GEnS from the MSFD. Showing causes (blue) and consequences (red)
Figure 20  Zoomed-in view of the causes (blue boxes) and consequences (red boxes) (top half of diagram). Life stages of the project which contribute towards each cause are given in blue text below the cause.
Figure 21  Zoomed-in view of the causes (blue boxes) and consequences (red boxes) (bottom half of diagram). Life stages of the project which contribute towards each cause are given in blue text below the cause.
Figure 22  Bow Tie scheme showing the prevention measures (to the left of the central hazard) and the mitigation measures (to the right of the central hazard). Zoomed in views follow.
Figure 23  Zoomed in view of the top left section of the diagram. Causes are shown in the blue boxes and possible prevention measures are shown to the right of the causes.
Figure 24  Zoomed in view of the top right section of the diagram. Consequences are shown in the red boxes and possible mitigation measures are shown to the left of the consequences. Escalation factors are shown in the yellow hanging boxes. These are factors which may cause a mitigation measure to fail or be less effective.
Figure 25  Zoomed in view of the bottom left section of the diagram. Causes are shown in the blue boxes and possible prevention measures are shown to the right of the causes.
Figure 26  Zoomed in view of the bottom right section of the diagram. Consequences are shown in the red boxes and possible mitigation measures are shown to the left of the consequences. Escalation factors are shown in the yellow hanging boxes. These are factors which may cause a mitigation measure to fail or be less effective.
Focused example of causes and consequences in the MSFD/GEnS Bow Tie

This example considers in detail just two causes from vein 2: (1) changes to biological diversity and, (2) marine litter, and two of the potential consequences: (1) permanent species distribution changes and (2) permanent habitat distribution changes (Figure 27). Note that any of the consequences in Figure 19 could occur as a failure to meet MSFD GEnS targets, this example just explains two options in depth.

If the operation of wind farms in the Dogger Bank areas of the North Sea causes changes to biological diversity (through disturbance of the sea bed, scaring away fish and mammals, disrupting bird migrations etc), it could result in the responsible Member State failing to meet the GEnS requirements of the relative descriptor (in this case, Descriptor 1, Biodiversity) under the MSFD. Consequences that could occur as a result of the loss of GEnS could be: (1) permanent changes in species distribution, as measured by the MSFD in terms of range/pattern/area; (2) permanent changes to habitat distribution as measured in terms of range or pattern, or (3) the Member State could face legal action (infraction proceedings) and be fined for the breach of GEnS. To help prevent these consequences, certain legislative barriers are in place. These come in the forms of both international conventions, that individual countries may sign up to of their own volition which then with enabling legislation become a legal requirement, and EU directives which are mandatory for all Member States of the European Union. These legal requirements are then translated into individual Member States’ governance systems through enabling regulations, e.g. the Wildlife and Countryside Act of 1981 in the UK. Such State level regulations are not covered by this top-level Bow Tie as there would be too many to list here and each country will have similar policies. These EU and International level agreements, as translated into State level regulations should be sufficient preventative measures to mean a loss of GEnS does not occur, hence other preventative barriers (e.g. operational measures, construction measures) are not listed here as preventative methods as they should form an inherent part of adhering to the legal requirements of the Conventions and Directives.

To prevent a change in biodiversity occurring, which would result in a loss of GEnS, the main legislative tools are: (1) The International Convention on Biological Diversity, (2) the Ramsar Convention, (3) the Bern Convention, (4) the Ospar Convention, (5) The EU MSFD, (6) The EU Habitats Directive, (7) The EU Birds Directive. Examples of consequences that could occur as a result of a failure to maintain GEnS could be (1) permanent species distribution changes (2) permanent changes to habitat distributions, (3) the Member State is put into infraction proceedings because of the breach of GEnS conditions.

To prevent an increase in marine litter occurring, through an increased input of materials into the system, which would result in a loss of GEnS, the main legislative tools are: (1) the OSPAR Convention and (2) The EU MSFD. Examples of possible consequences could again be: (1) permanent species distribution changes, (2) permanent changes to habitat distributions, (3) the Member State is put into infraction proceedings because of the breach of GEnS conditions.

The prevention measures described above all have the aim of reducing the likelihood of the central event/hazard from happening. Therefore they should all help to reduce the probability that the requirements of the MSFD will fail to be met in the North Sea as the result of offshore wind. However, should this still occur, the right hand side of the Bow Tie diagram indicates ways to mitigate the consequences (Figure 28).

Permanent changes to species distribution can be potentially mitigated by: (1) operating methods which aim to reduce the impact of noise during construction, for instance, soft-start procedures, bubble
curtains and acoustic deterrent devices; these may enable affected species to be able to move back into the area; (2) seasonal operating restrictions, for instance, operations could be shut down at times of migration; (3) scaring devices could be used to deter both flying and swimming species from collisions; (4) habitat offsetting could be used to provide alternative areas of habitat that would replace that lost or changed by wind farms; (5) large broodstock animals could be caught elsewhere and then released within the wind farm zone with the aim of rebuilding lost populations; (6) breeding programmes could be introduced where this would be applicable. Breeding programmes would aim to support population and community structure or to re-stock areas that have become devoid of certain species. However in the offshore marine environment, this may only be appropriate to species such as sea birds and maybe some fish. It would be inherently difficult to introduce breeding programmes for benthic infauna such as polychaetes.

Permanent changes to habitat distribution could be potentially mitigated by: (1) controlling release of sediments during construction works, e.g. through using devices such as bubble curtains or by operating only on a slack tide or when tides take any suspended sediment away from the area, (2) habitat offsetting, (3) habitat design measures, (4) habitat creation measures, or (5) by introducing further legislation that aims to recover any damage.

Some of these prevention and mitigation measures have escalation factors attached (yellow box, Figure 28). For example, introducing further legislation will require the legislation to be adopted and implemented by Member States for it to be effective.

If the Member State is put into infraction because of the failure to meet with the requirement of the MSFD, there are no mitigation measures that are applicable as all other prevention methods and mitigation methods should have already been employed by the Member State to prevent it reaching a state of environmental deterioration that is so great that legal action is the only remaining option.
Figure 27  Focused example from vein 2. Two causes that could lead to three potential consequences. Examples of legislative tools that are in place to prevent the contral hazard from happening are shown in the multi-coloured boxes. The life-stages of the wind farm that contribute towards each cause are shown in blue text below the cause.
Figure 28  Focused example from vein 2. Two causes that could lead to three potential consequences. Examples of potential tools that are in place to mitigate the consequences after the central hazard event occurs are shown in the multi-coloured boxes. The life-stages of the wind farm that contribute towards each cause are shown in blue text below the cause.
Discussion and conclusions

Risk Analysis that considers all aspects of wind power generation in the European Regional Seas is a complex task beyond the scope of this case study. Hence the Dogger Bank in the North Sea was chosen as an example of an area identified for large scale wind development in the near future. The Bow Tie method for risk assessment and management was chosen to see if this form of analysis would work for such an intricate case.

Under the umbrella of future climate change, the top-level ways in which the environment could affect the successful operation of the wind farm and the use of the wind resource were examined, as were the ways that the wind farm may affect the environment in the context of the Marine Strategy Framework directive (MSFD) descriptors of Good Environmental Status (GEnS).

Use of the Bow Tie approach has been successful in being able to map out all the aspects that are related to a particular event that we do not want to happen. In this case these two events have been:

1) the loss of renewable energy resources; the context of this Bow Tie was: ways that climate change may cause the environment to affect the wind farm;

2) changes to the environment in terms of the MSFD GEnS indicators; the context of this Bow Tie was: ways that the wind farm can affect the environment.

A strength of the Bow Tie software chosen for this analysis is that the diagrams are only the first stage in using the program. Complex information can be included in clickable boxes, as can links to relevant documentation. It is possible to make the diagram quantitative if probability information exists for the hazard under study. However given the nature of this case study, such information was not possible to include at the present time. Different levels of depth will be needed by different levels of an organisation, therefore the Bow Tie program serves a multifaceted purpose whereby the diagrams alone are sufficient to be used to disseminate to those who may only need to know the top-level outcome, this may be the public or the media for example. Those members of the organisation implementing changes and working on the logistics of the wind farm development can access all of the deeper information to help make more informed decisions and improve and edit the risk assessment as more information becomes available.

A potential drawback is the apparent linear nature of the diagram. Sometimes not all mitigation or prevention measures are needed, or sometimes more than one may be applied simultaneously. This is not evident from the diagrammatic format of the Bow Tie Risk Assessment and may mislead someone who has not previously encountered the Bow Tie scheme.

Furthermore, working under the MSFD means that change to populations, habitats and species are seen as negative. It is well known that wind farms, especially the bases and scour protection, can be used for habitat creation, albeit often a different habitat to what was there before (Langhammer and Wilhelmsson, 2009; Wilson and Elliott, 2009), as well as for co-locating other marine activities to ease demands on limited space (Christie et al., 2014).
In the future, to make a Bow Tie a more robust and singularly useful tool for both scientists and managers, modelling is required to play a role in both informing, and in developing the Bow Tie model. At its most straightforward, the Bow Tie works as a qualitative model for displaying links between causes, hazards and consequences (as seen here in this report), but modelling tools provide numerical elements which can be used to enhance the Bow Tie by making it quantitative. For instance, climate modelling could predict a certain mean global temperature rise over the next 100 years under a certain set of conditions. This temperature change would be the central event, which would lead to a certain set of potential consequences each with probabilities of happening for those set of conditions. The modelling provides a prediction of how incorporating prevention and mitigation measures would reduce these probabilities, which can then be mapped onto the Bow Tie and can give us effectively a ‘before’ and ‘after’ picture of how management measures can reduce negative consequences or even prevent the central event from happening at all.

Complimentary to modelling as a way of informing Bow Tie development is the role of scenario testing. This enables the production of the magnitude of the changes and the system ability to respond to the changes and recover from the changes, dependent on certain scenarios.

To fully incorporate everything in a system, from the top-level changes as described here, to specific situations such as the impacts of rock-armour style scour protection on sandy benthic infauna, on one Bow Tie diagram is not possible. Where one Bow Tie diagram may be sufficient for a small case study, for instance the effects of laying a cable route over a specific sandy beach, it would not be sufficient for tracing the effects of that cable route from a remote offshore wind farm to the landfall point a few km inland, across all the various habitats and taking into account all the users and uses of the sea bed in between. In this case, a nested and chained Bow Tie approach can be used and several Bow Ties linked together to form one overall diagrammatic model of the system in which users can click and be shown only the links that are relevant to the cause, consequence or even the control measure of question. This way of linking Bow Tie diagrams together allows for the incorporation of the DPSIR (DPSWR) principles and would enable users to see in a simple way how one Pressure may lead to many State changes (on the natural system), and that each individual state change could lead to a range of potential Impacts (on the human system), across different environmental scales. The Responses are then incorporated into the model as the various prevention and mitigation measures.

This is a top-level risk assessment that has attempted to encompass the entire system, hence by its nature it is generic. If Bow Tie was chosen to be used as a complete risk management method then more precise Bow Ties could be constructed that allow different aspects of the system to be analysed in a greater level of detail. As our knowledge and understanding of the impacts caused by and to wind farms progresses, the contents and prominence of risk assessments will change and the Bow Tie can be adapted to accommodate these by building on the analysis here. Furthermore, the Bow Tie can be enhanced by adding quantitative elements should such information become readily available.

Although this exercise is successful as a proof of concept and has shown that the Bow Tie scheme is appropriate for mapping out causes, consequences, hazards and risks caused by and to wind energy in the North Sea, further development is needed to determine the overall significance or acceptability of the causes and consequences under specific scenarios.
References


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Appendix 1

List of regional level legislation, agreements and conventions that are applicable in full or part to wind farm sites

The EU and international level legislation with relevance for wind energy includes the following:

**Full**


The EIA directive aims to define a legal framework for assessing the environmental effects of both public and private projects. It requires Member States to adopt all measures necessary to ensure that, before consent is given, projects likely to have significant effects on the environment by virtue of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects. The Directive distinguishes between projects, where an EIA is mandatory and projects where the national authorities decide on the need for an EIA after a screening procedure. In line with the requirements of the Directive an EIA is to be carried out in support of applications to develop certain types of project as listed in the Directive at Annexes I and II. Offshore wind-farm developments are listed in Annex II as ‘installations for the harnessing of wind power for energy production (wind-farms)’. Entries in Annex II are only require an EIA should the Member State deem it worthy of one. However, in practice, modern large wind energy installations always require an EIA (Hansen, 2011; OSPAR, 2008).

**Directive 2001/42/EC: The Directive on Strategic Environmental Assessment (SEA).**

SEA involves the environmental assessment of policies, plans and programmes. The aim of strategic environmental assessment is to provide decision makers and stakeholders with information on the potential environmental impacts of these programmes, so that changes can be made to make them environmentally robust. SEA and EIA are similar in many respects, however in comparison to EIA which involves monitoring and field visits, SEAs are desk based studies, based on existing available information. SEA focuses only on plans whereas EIA focuses on individual installations. The SEA also covers geographical areas compared to site specific EIA.

Normally wind energy projects fall outside of the scope of SEA, however very large projects may require an SEA (Hansen, 2011).


The Marine Strategy Framework Directive (MSFD) was adopted in July 2008 with the aims of at achieving or maintaining a good environmental status of the marine environment by 2020 at the latest, to apply an ecosystem approach, and to ensure that pressure from human activities is compatible with good environmental status. This is achieved through integrating the concepts of environmental protection and sustainable use. Where Member States share an area of the marine environment they are required to co-operate to achieve good environmental status. According to Article 13 of the Marine Strategy Framework Directive the Member States are obliged, in respect of the region concerned, to identify measures, which need to be taken in order to achieve or maintain good environmental status.
Directive 2009/28/EC amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC: The promotion of the use of energy from renewable sources. This Directive establishes a common framework for the use of energy from renewable sources in order to limit greenhouse gas emissions and to promote cleaner transport. To achieve this, national action plans are defined, as are procedures for the use of biofuels. Each Member State has a target calculated according to the share of energy from renewable sources in its gross final consumption for 2020.

The EU and Aarhus Convention on Access to Environmental Information and Public participation (UN ECE, 1998). The Aarhus Convention extends and incorporates several EU Directives – particularly the Directive 2003/4/EC on access to environmental information and Directive 2003/35/EC on public participation. Following the Aarhus Convention Article 2, the public in general must have access to environmental information, the affected public as well as NGOs promoting environmental protection must be allowed to participate in the decision process (EU, 2014).

Part

Directive 2009/147/EC on the conservation of wild birds, codifying Directive 79/409/EEC. Commonly known as “The Birds directive.” The Birds Directive is the oldest piece of conservation legislation in EU with the original Directive being adopted in 1979, as a response to increasing concern about the declines in Europe's wild bird populations resulting from pollution and loss of habitats, as well as giving recognition that wild birds, are a shared heritage of the Member States and that their effective conservation required international co-operation. The Birds Directive aims to protect the habits of endangered and migratory species by establishing a network of Special Protection Areas, which form part of the Natura 2000 network. Article 5 of the Birds Directive requires that Member States should prohibit activities that directly threaten birds, including: Deliberate killing or capture by any methods, and, Deliberate disturbance of these birds particularly during the period of breeding and rearing as far as this would have a negative effect on the birds. These are likely to be the main parts of the Birds Directive guidance that are relevant to wind farm developments.


Articles 12 and 13 of the Habitats Directive oblige the Member States to take measures to protect the species listed in Annex IV of the Directive by prohibiting

- Deliberate killing or capture of protected animals by any method
- Deliberate disturbance of protected animals, particularly during breeding, rearing, hibernation and migration
- Deliberation destruction or taking of eggs in the wild from protected animals
- Deterioration or destruction of breeding sites or resting places for protected animals
- Deliberate picking, collecting, cutting, uprooting or destruction of protected plants in the wild
- Keeping, sale and transport of specimens – protected animals or plants - from the wild
However, deviations from the above general protection rules are allowed in some circumstances. These conditions are defined in Article 9 of the Birds Directive. When regarding wind farm development it is primarily item (a) ‘in the interest of public health and safety’. The reasons for having deviations from the general rules in the Habitats Directive are stated in Article 16, and for wind energy development it is primarily item (1c) on ‘other imperative reasons of public interest’, which is likely to be applied.


The Noise Directive aims to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise”. It also aims to provide a basis for developing EU measures to reduce noise emitted by major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery. Hence the noise cause by construction operating and decommissioning of a wind farm is likely to come under the concern of the Noise Directive.

In addition to the above EU level legislation that applies to wind farm developments, several international conventions and agreements regarding nature and biodiversity have effect for the EU and its Member States and will apply to the installation of wind energy projects in Europe:

**Convention for the Protection of the Marine Environment of the North-East Atlantic – Commonly known as “The OSPAR Convention”:**

The OSPAR Convention aims to protect the marine environment of the North-East Atlantic. It came into force in 1998 and merged the 1974 Oslo Convention (Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft) and the 1978 Paris Convention (Convention for the Prevention of Marine Pollution from Land-Based Sources).

The Convention has been signed and ratified by all of the Contracting Parties to the original Oslo or Paris Conventions (Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland) and by Luxembourg and Switzerland.

The OSPAR Convention includes the following Annexes:
- Annex I: Prevention and elimination of pollution from land-based sources;
- Annex II: Prevention and elimination of pollution by dumping or incineration;
- Annex III: Prevention and elimination of pollution from offshore sources;
- Annex IV: Assessment of the quality of the marine environment; and
- Annex V: Protection and conservation of the ecosystems and biological diversity of the maritime area.

The first Ministerial Meeting of the OSPAR Commission at Sintra, Portugal in 1998 adopted Annex V to the Convention, to extend the cooperation of the Contracting Parties to cover all human activities that might adversely affect the marine environment of the North-East Atlantic. Nevertheless, programmes and measures cannot be adopted under the Convention on
questions relating to fisheries management and there is a preference for issues related to shipping to be dealt with by the International Maritime Organisation.

The Bern Convention on the Conservation of European Wildlife and Natural Habitats.
The Bern Convention entered into force in 1982. It is a binding international legal instrument in which covers most of the natural heritage of the European continent and some States of Africa. The aim of the Bern Convention is to conserve wild flora and fauna and their natural habitats and to promote European co-operation in that field of nature conservation. Particular importance is placed on the need to protect endangered natural habitats and endangered vulnerable species, including migratory species. As of April 2014, 45 Member States of the Council of Europe and 5 African States have signed to the Convention. The Bern Convention adopted a recommendation on the effects of wind farms on migratory species of mammal and birds in 2002 (Council of Europe, 2003). Location is considered vitally important to avoid damaging impacts of wind farms on birds and there should be precautionary avoidance of locating wind farms in officially designated areas such as Natura 2000, Ramsar sites and similar protected areas (Hansen, 2011).

The UNCLOS was opened for signature in 1982, coming into force in 1994, and since has been ratified by 166 parties, which includes 165 states (163 member states of the United Nations plus the Cook Islands and Niue) and the European Union. It sets out comprehensive regime of law for the world’s oceans and seas and establishes rules governing all uses of the oceans and their resources. The overarching idea is that all problems of ocean space are closely interrelated and need to be addressed as a whole. UNCLOS divides the seas and oceans into several zones with different rights and obligations. Under the convention, coastal States have sovereignty over their territorial sea extending 12 nautical miles from the coastline, however foreign vessels are allowed “innocent passage” through this zone. Coastal States have additional sovereign rights in a 200-nautical mile exclusive economic zone (EEZ) with respect to natural resources and certain economic activities, and exercise jurisdiction over marine science research and environmental protection. Although the coastal state has full jurisdiction within its territorial waters, certain articles of the convention may hamper the development of new wind farms within this zone. For example, all other States have freedom of navigation and overflight in the EEZ, as well as freedom to lay submarine cables and pipelines, and, States are bound to prevent and control marine pollution and are liable for damage caused by violation of their international obligations to combat such pollution (UN, 2013).

The Convention on Biological Diversity (CBD):
The CBD came into force in 1993 and is a global treaty adopted at the World Summit in Rio de Janeiro in 1992. The convention has three major objectives: 1) Conservation of the biological diversity, 2) The sustainable use of the components of biological diversity, and 3) The fair and equitable sharing of the benefits arising out of the use of genetic resources. Under the Convention, although States have the sovereign right to exploit their own resources pursuant to their own environmental policies, they have a responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.

The Ramsar Convention on Wetlands of International Importance:
The Ramsar Convention is an intergovernmental treaty adopted in 1971 and amended in 1982 and 1988. The Ramsar Convention is the only global environmental treaty that deals with a particular ecosystem and provides a framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. The “wise use” concept of the convention is defined as “the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development.” The broad definition of wetlands under the Ramsar convention includes estuaries, deltas and tidal flats, near-shore marine areas, mangroves and coral reefs, therefore may be applicable to certain wind farm development projects.

Convention on International Trade in Endangered Species of Wild Fauna and Flora – CITES:
Whilst the aim of the CITES Convention is to protect endangered plant and animal species from illegal trade and over-exploitation, it may be indirectly applicable to wind farm sites by curtailing restrictions on trade in international species which may be able to use wind farms to gain a foothold in an otherwise unreachable area. Releases of “pet” animals are one of the ways in which alien species become established in a new area and limiting trade can be one way to prevent such events.

CITES was initiated at an IUCN General Assembly in 1963 and concluded at Washington in 1973 and came into force in 1975. It has been ratified by well over 100 countries world-wide, including the UK in 1976. Commercial trade in endangered species listed in Appendix I is forbidden. Controlled trade is allowed for species which, although not currently threatened with extinction, may become so unless restrictions are applied, listed in Appendix II. Where a Party to the Convention protects one of its native species from over-exploitation and seeks the assistance of other Parties in implementing these controls, it can list such species in Appendix III.

The HELCOM Convention on the protection of the marine environment of the Baltic Sea Area. Also known as the Helsinki Convention:
The HELCOM convention was adopted in 1980 and revised in 1992. The convention protects the Baltic Sea, the sea bed and all inland waters of its catchment area. HELCOM is considered as a coordinating platform for implementing the MSFD in the Baltic region.
## Appendix 2

**Typology of Hazards in Coastal and Coastal Wetland Areas (from Elliott et al., 2014)**

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Surface hydrological hazards</td>
<td>Natural but exacerbated by human activities</td>
<td>High tide flooding, spring tide and equinoctial flooding; flash flooding, ENSO/NAO patterns</td>
</tr>
<tr>
<td>B) Surface physiographic removal by natural processes - chronic/long-term</td>
<td>Natural but exacerbated by human activities</td>
<td>Erosion of soft cliffs by slumping</td>
</tr>
<tr>
<td>C) Surface physiographic removal by human actions - chronic/long-term</td>
<td>Anthropogenic</td>
<td>Land claim, removal of wetlands for urban and agricultural area</td>
</tr>
<tr>
<td>D) Surface physiographic removal - acute/short-term</td>
<td>Natural</td>
<td>Cliff failure, undercutting of hard cliffs</td>
</tr>
<tr>
<td>E) Climatological hazards - acute/short-term</td>
<td>Natural but exacerbated by human activities</td>
<td>Storm surges, cyclones, tropical storms, hurricanes, offshore surges, fluvial and pluvial flooding</td>
</tr>
<tr>
<td>F) Climatological hazards - chronic/long term</td>
<td>Natural but exacerbated by human activities</td>
<td>Ocean acidification, sea level rise, storminess, ingress of seawater/saline intrusion</td>
</tr>
<tr>
<td>G) Tectonic hazards - acute/short-term</td>
<td>Natural</td>
<td>Tsunamis, seismic slippages,</td>
</tr>
<tr>
<td>H) Tectonic hazards - chronic/long-term</td>
<td>Natural</td>
<td>Isostatic rebound</td>
</tr>
<tr>
<td>I) Anthropogenic microbial biohazards</td>
<td>Anthropogenic</td>
<td>Sewage pathogens</td>
</tr>
<tr>
<td>J) Anthropogenic macrobial biohazards</td>
<td>Anthropogenic</td>
<td>Alien, introduced and invasive species, GMOs, bloom-forming species</td>
</tr>
<tr>
<td>K) Anthropogenic introduced technological hazards</td>
<td>Anthropogenic</td>
<td>Infrastructure, coastal defences</td>
</tr>
<tr>
<td>L) Anthropogenic extractive technological hazards</td>
<td>Anthropogenic</td>
<td>Removal of space, removal of biological populations (fish, shellfish, etc); seabed extraction and oil/gas/coal extraction leading to subsidence</td>
</tr>
<tr>
<td>M) Anthropogenic acute chemical hazards</td>
<td>Anthropogenic</td>
<td>Pollution from one-off spillages, oil spills</td>
</tr>
<tr>
<td>N) Anthropogenic chronic chemical hazards</td>
<td>Anthropogenic</td>
<td>Diffuse pollution, litter/garbage, nutrients from land run-off, constant land-based discharges, aerial inputs</td>
</tr>
</tbody>
</table>