PLASMAR

Bases para la planificación sostenible de áreas marinas en la Macaronesia

Finding the Balance of Blue Growth Sustainable Development within Ecosystem Approach (2.1.1 c&d). Analysis of the Offshore Wind Industry in Macaronesia under MSFD

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1 Introduction and context within the PLASMAR project & MSP process

The marine environment will play a key role in hosting new energy strategies, including the offshore wind sector. However, it is unclear how the construction, operation and decommissioning of Offshore Wind Farms (OWF) and related infrastructure will impact the marine environment and marine ecosystem services (Lindeboom et al., 2011; Papathanasopoulou et al., 2015; Raoux et al., 2017).

PLASMAR project aims at the definition and proposal of robust scientific methodologies in support of Maritime Spatial Planning (MSP) and Blue Growth in the three archipelagos included in the Macaronesian Region, searching for smart solutions to harmonize Blue Growth development of diverse maritime sectors and the conservation of its natural marine heritage.

This study uses the framework established by Marine Strategy Framework Directive 2008/56/EC (MSFD), on Good Environmental Status (GES), to analyse what are the significant risks and environmental issues associated with the offshore wind sector.

We have followed 11 quality descriptors, and related 42 criteria elements to deliver a detailed review of scientific and technical reports related to the offshore wind sector. The reviews included the results of revised reports setting out the potential environmental problems / issues that can be expected during the construction phase, during the OWF operational phase, as well as the decommission phase. Additionally, the outputs of a specific workshop conducted in 2017 (as part of the EU EcoAqua ERA-Chair project), when only 11 quality descriptors were considered, was incorporated as first approach to OWF and MSP. Additionally, experts on environmental impact assessment and offshore wind engineering experts were consulted to clarify specific topics. Therefore, for each environmental issue identified, the spatial extent of environmental impact was analysed, (engineering) solutions for the environmental pressures identified, and mitigation for specific impacts established. Finally, we attempted to identify the most efficient techniques for monitoring, that can provide robust information about the OWF practices and whether or not, these exceed sustainable limits on marine environment.

Within this study we delivered a checklist, following the GES framework, that provides information about what types of impacts can be expected, what environmental issues can be avoided and what measures can be implemented to mitigate those impacts.

The results of this study include valuable information for the Environmental Impact Assessment (EIA) process, listing topics that should be elaborated within the Environmental Impact Study (delivered by promoter) and included in the Environmental Impact Decision. The study established that the promoter requiring marine space and related licenses for building and operating an OWF business, needs to develop a checklist and provide important information for assessing the associated risks. Particularly, in the case where the project will be approved/refused due environmental issues. Furthermore, it lists topics that should be included and analysed in detail in the Environmental Impact Study, which is a foundation for administrative decisions.

The application of the GES checklist by competent authorities (licensing the use of the marine space), will allow them to define:

- Trade-offs: Local economy *vs* marine environment;
- The main environmental issues and if they are properly identified in the Environmental Impact Study delivered by promoter in the EIA process;
- The alternatives and how it will be possible to avoid pressures and related impacts;
- If there are mitigation measures and how they can be applied; and
- The type of monitoring necessary to ensure that OWF does not exceed the sustainability thresholds for all three phases (construction, operations and decommission).

The application of the GES checklist should speed up the development of the Environmental Impact Decision on OWFs, by listing potential environmental issues and solutions. The GES marine environment is conceptually “modelled” through 11 quality descriptors and 42 criteria elements. These are used to identify the environmental components that should be included, considered and elaborated in the EIA process, including EI Study and EI Decision.

The MSFD GES framework (MSFD & Commission Decision 2017/848/EU) provides a more elaborate framework for assessment than the EIA standard (including broad requirements of Directive 2011/92/EU) for the offshore wind sector, as it factors in the most significant and vulnerable components of the marine environment.

Moreover, by integrating the GES framework into the EIA process, we are supporting implementation of the environmental policies that applies on the sea (mainly MSFD, but also Habitat and Bird Directives, WFD, SEA Directive?), including the environmental targets within the offshore wind sector development. Studies developed within the EIA process provide valuable information on the environment that can or should be reused for the 6 year assessment of marine waters, as required by MSFD.

The GES checklist for OWF is developed within the PLASMAR project, as part of the multi-component methodology, developed and applied for a MSP zoning process. This study covers environmental components - parameters for the multi-parameter analysis for zoning of offshore wind sector. Applying results and the related zoning method with appropriate data will allow the identification of potential areas for OWF development with the lowest likely environmental impact. In the later multi-component analysis, other parameters, covering the land-sea interactions, other maritime sectors, oceanography etc., will be included. Thus, final selection of the allocated zones for the offshore wind sector will be agreed through an integrated stakeholder, MSP process.

II. Methodology

2 Methodology applied

State of art of OWF environmental impacts and possible environmental friendly solutions were gathered mainly through the review of scientific and technical publications, the inputs generated during the PLASMAR workshop on GES, and maritime activities inside MapSIS 2017 International Conference (as part of the EU EcoAqua ERA-Chair project), and interviews and meetings with experts from the offshore wind energy sector and experts in marine impact assessment.

This report is organised following the structure provided by the Marine Strategy Framework Directive (MSFD), with the aim of identifying maritime activity environmental pressures/impacts that are related to the GES quality descriptor/criteria elements. For the purpose of this report, we have focused on official technical reports and scientific publications related to offshore wind sector taking into consideration the 11 quality descriptors of GES and their related 42 criteria. These reviews included the potential environmental problems/issues that can be expected during the construction phase, during the OWF operational phase, and the decommission phase. For each environmental issue identified, the spatial extent of the environmental impact was analysed, the availability or not of a solution (engineering) for the environmental pressure, and how that specific impact can be mitigated. Finally, we try to identify the most efficient techniques for monitoring, that can provide robust information about OWF practices and they exceed sustainable limits on the marine environment.

The complete list of criteria to be analysed is acquired from the Commission decision document on criteria and methodological standards on GES of marine waters and specifications and standardised methods for monitoring and assessment (2017/848/EU)

(Available at:https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1495097018132&uri=CELEX:32017D0848).

This legal document is a product of the revision and related amendment of MSFD and the older Commission Decision on GES 2010/477/EU.

GES is defined in 14 tables (one table per Quality Descriptor, plus 4 tables on biodiversity). This is adopted for the analysis as follows:

1. Environmental impact, values: YES/NO; if YES, environmental impact was explained including the references and sources of information;

2. Environmental impact spatial extent, values:
   Impact area narrower than operative maritime activity area;
   Impact area equal to operative maritime activity area;
   Impact area broader than operative maritime activity area;

3. Maritime Activity pressure solution, values: YES/NO; if YES, a short explanation needs to be included.

4. Impact mitigation measures, values: YES/NO; if YES, a short explanation needs to be included.

5. Monitoring method available: values: YES/NO; if YES, a short explanation of the monitoring method needs to be included.

Table 1

QD2 Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD2	Newly-introduced non-indigenous species.	D2C1					
	Abundance and spatial distribution of established non-indigenous species, contributing significantly to adverse effects on particular species groups or broad habitat types	D2C2 — Secondary					
	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species, particularly invasive non-indigenous species.	D2C3 — Secondary					

In the analysis three consecutive phases were considered: a) The OWF facility construction phase, b) the operational phase, and c) the decommission phase of the offshore wind energy production site.

Most of the reports reviewed for this project described experiences, solutions and monitoring techniques applied in the context of the North Sea and the Baltics. The analysis sought to capitalise on the experiences obtained in northern marine areas of the continental Europe and to apply the principal outputs to the Macaronesian Region, which, it should be noted is a significantly different marine environment.

III. Quality Descriptors VS Good Environmental Status (applied to the Offshore Wind Sector)

3 Analysis descriptor 2: Non-indigenous Species

The Convention on Biological Diversity defines Non-Indigenous Species (NIS) as species whose introduction or spread threatens biodiversity. NIS are species introduced outside their natural past or present range, which might survive and subsequently reproduce. After settlement, if they become dominant, the introduction or spread might affect the structure, composition and biomass production of local / regional ecosystems. The introduction of these species is enhanced in situations where the exchange of people or goods takes place between countries and continents, for example, by shipping or transfer of large infrastructures (i.e. fouling of hulls and other submerged underwater parts).

Table 2

QD2 Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD2	Newly-introduced non-indigenous species.	D2C1	yes	broader	yes	yes	Yes
	Abundance and spatial distribution of established non-indigenous species, contributing significantly to adverse effects on particular species groups or broad habitat types	D2C2 — Secondary	yes	broader	yes	yes	Yes
	Proportion of the species group or spatial extent of the broad habitat type which is adversely altered due to non-indigenous species, particularly invasive non-indigenous species.	D2C3 — Secondary	yes	broader	yes	yes	Yes

3.1 D2C1 Newly-introduced, Non-indigenous Species

Modified habitats such as the wind turbines structures – similar to artificial reefs - can be colonised by NIS, dispersed from natural or anthropogenic sources. Placement of human-made structures and the subsequent modification of the natural habitat is identified as facilitators of non - indigenous/invasive species propagation (Belleri & Airoldi

2005, Glasby et al., 2007). Thus, some of the recommendations for managing impact by NIS at artificial reefs can be applied to OWF (REFERENCE??). In rletion to the NIS issues, wind turbine offshore maritime structures do not have a direct impact on the marine environment, but indirectly increase vectors enabled by anthropogenic introduction (ballast waters, fouling on ship hulls, marine debris, etc.) or natural introduction by means such as currents and loop current eddies. Moreover, the introduced hard substrata of the OWF has been shown to play an important role in the establishment and the expansion of the population size of the NIS (Kerckhof et al., 2011).

Wind turbine structures provide a new, hard substrate and vertical profile where none previously existed, thereby, potentially changing the distribution of species including NIS (Langhamer, 2012; De Mesel et al.,2015). Additionally, the network between turbines within an OWF may also create non-indigenous species corridors for linking previously unconnected areas (Sheehy and Vik, 2010).

Shanley and Vik (2010) proposed linking spatial data with biophysical modeling, to predict species introductions and their impacts, and to anticipate introduction species vectors. They argue that the outputs of this model would help to identify the likely sources of the introduction, the spreading vectors (such as new species corridors), and sites for turbines/wind farms that have reduced potential for additional NIS transfers. These results can support mitigation measures, as effective response programs to predict where invasive species are likely to result.

The following are the main recommendations for managing and mitigating the impact of NIS from OWF:

- Capacity building and training for OWF staff to identify local marine species and the arrival and distribution pattern of NIS in wind turbine structures, and networks;
- Distribution of NIS identification information to OWF program managers, end users, and especially to maintenance personal as divers, who may provide early warning of incursion;
- Efficient monitoring method of NIS appearance or propagation based on the above-mentioned measures;
- Development of GIS for tracking reported NIS occurrence and for selecting new wind farms sites;
- Avoiding (and/or carefully considering) long, contiguous networks of turbines that may provide corridors ready for NIS transfer; and
- Avoiding long distance transfers of materials with intact fouling communities.

It should be noted that, once the lease for the OWF site expires, or the installation reaches its end of life, few countries (such as Denmark) include the possibility for partial or complete decommissioning.

3.2 D2C3 & D2C4 (Secondary criteria)

The references and text that applies to the D2C1 criterion applies equally to the following criteria: D2C3 & D2C4.

4 Analysis Descriptor 3: Commercial Fish and Shellfish

Commercially exploited fish and shellfish are all living marine resources targeted for economic profit. In scientific terms, the GES level applied to Descriptor 3 has various implications: Stocks should, (1) be exploited sustainably and consistent with high long-term yields, (2) have full reproductive capacity in order to maintain stock biomass, and (3) be maintained (or increased) based on the proportion of older and larger fish/shellfish as an indicator of a healthy stock.

Table 3

QD3 Populations of all commercially-exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock							
	Criteria (element)	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD3	The *Fishing mortality* rate of populations of commercially-exploited species	D3C1	No				
	The *Spawning Stock Biomass* of populations of commercially-exploited species	D3C2	No				
	The age and size distribution of individuals in the populations of commercially-exploited species is indicative of a healthy population. This shall include a high proportion of old/large individuals and limited adverse effects of exploitation on genetic diversity.	D3C3	No				

4.1 D3C1, D3C2, D3C3 Fishing Mortality, Spawning Stock Biomass and Age & Size Distribution of Commercially-exploited Species

OWF impacts on fish and shellfish include both negative and positive effects (Langhammer et al., 2018). OWF foundations and scour protections on the seabed can lead to increased habitat complexity that affect certain fish species and communities positively (Langhamer, 2012; Bergström et al., 2013; Stenberg et al., 2015). In a similar way, wind turbines, both fixed and floating facilities, may act as artificial reefs and/or fish aggregating devices that concentrate marine fish and facilitate their capture (Castro et al. 1999; Fayram & de Risi, 2007; Wilhelmsson et al., 2006). Furthermore, OWFs may create fisheries exclusion zones acting as marine protected areas prohibiting e.g. trawling and gillnetting (Ashley et al., 2014), and have been shown to lead to higher abundance and larger specimens of certain fish, including commercially-exploited species (Degraer et al., 2011; Lindeboom et al., 2011; Reubens et al., 2011). This indirect “reserve effect” can lead to increased local biomasses, not only for the commercial species, but also to whole ecosystem (Leonhard et al., 2011, Lindeboom et al., 2011, Shields & Payne, 2014).

On the other hand, combining OWF with fisheries can be expected to increase local mortality rates of fish populations, if an increased aggregation close to the wind turbine foundations only serves to enhance catch rates (Polovina, 1989; Grossman et al., 1997, Pickering & Whitmarsh, 1997; Reubens et al., 2014).

Impact related to the commercially-exploited species is reduced on their spatial distribution (Floeter et al., 2017) and stress by noise and electromagnetic field emission (Wahlberg & Westerberg, 2005; 2007; Gill et al., 2009; Kikuchi, 2010). To date there does not appear to be robust scientific research or evidence on increased mortality, decreased spawning stock biomass or unhealthy populations of commercially-exploited species due operational OWFs, probably because there are few OWFs already installed and they are relatively recent development in the marine ecosystem, with little time to determine such potential effects. Nevertheless, these effects should be further investigated, as they can influence growth, migration, survival, and/or reproductive capacity of commercially-exploited fish in the Macaronesia (such as tunas, sardines, amberjacks, and sparids, among other species).

5 Analysis Descriptor 5: Eutrophication

Eutrophication is a chemical process driven by the enrichment of certain water bodies by the concentration of diverse nutrients, especially compounds of nitrogen and/or phosphorus. This may lead toward changes in the water column and in the benthic communities, such as increased growth, primary production and biomass of algae, modifications in the balance and density of some organisms, and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and biodiversity and/or the sustainable provision of goods and services from coastal and marine ecosystems.

Table 4

QD5 Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD5	Nutrient concentrations (Dissolved Inorganic Nitrogen (DIN), Total Nitrogen (TN), Dissolved Inorganic Phosphorus (DIP), Total Phosphorus (TP)) are not at levels that indicate adverse eutrophication effects.	D5C1	No				
	Chlorophyll a concentrations are not at levels that indicate adverse effects of nutrient enrichment.	D5C2	No				
	The number, spatial extent and duration of harmful algal bloom (e.g. cyanobacteria) events are not at levels that indicate adverse effects of nutrient enrichment.	D5C3 — Secondary					
	The photic limit (transparency) of the water column is not reduced, due to increases in suspended algae, to a level that indicates adverse effects of nutrient enrichment.	D5C4 — Secondary					

	The concentration of dissolved oxygen is not reduced, due to nutrient enrichment, to levels that indicate adverse effects on benthic habitats (including on associated biota and mobile species) or other eutrophication effects.	D5C5	No				
	The abundance of opportunistic macroalgae is not at levels that indicate adverse effects of nutrient enrichment.	D5C6 — Secondary					
	The species composition and relative abundance or depth distribution of macrophyte communities achieve values that indicate there is no adverse effect due to nutrient enrichment including via a decrease in water transparency	D5C7 — Secondary					
	The species composition and relative abundance of macrofaunal communities, achieve values that indicate that there is no adverse effect due to nutrient and organic enrichment	D5C8 — Secondary					

5.1 D5C1 Nutrient Concentrations

There are many studies connecting the extraction of energy from the offshore wind turbines and change in the vertical hydrodynamics of water bodies, such as upwelling and downwelling processes (Broström 2008, Nerge & Lenhart 2010, Ludewig 2015). Studies delivered by Cazenave et al. (2016), Carpenter et al. (2016) and Floeter et al. (2017) show that currents flows (tidal, wind, storm) passing OWF foundation structures generate a turbulent wake that contributes to a vertical mixing and an increase of nutrient concentrations at the surface. While these processes can increase concentration of nutrients in surface layers, they are also significant in the shallow seas and stratificated layers of the ocean. Taking into consideration the geographic characteristics of the different archipelagos considered in these studies, the effects identified may not be relevant in Macaronesia since the bathymetry of the islands quickly reaches deep-waters.

5.2 D5C2 Chlorophyll *a* Concentrations

Van der Molen et al. (2014), when applying physical–biogeochemical model, argued for an increased primary production due to lower suspended matter concentrations and consequent, higher light availability when OWF turbines are operating. Further, on the basis of the satellite images, the same authors suggested that primary production may be decreased by higher turbulence levels induced by turbine foundations. The empricial study by Floeter et al. (2017) provides results on the lower primary production in the OWF area. The significance and consequences of OWF-increased primary production remains a task for further investigation, but most probably can be concluded in a similar way as for the D5C1, as this criterion could be irrelevant in the Macaronesia Region.

5.3 D5C5 Concentration of Dissolved Oxygen

There are scientific reports that relate operational OWF and reduced dissolved oxygen concentration on the local scale with low mesoscale impacts. These reports relate to the designated and potential OWF areas in Baltic Sea, that have significant stratification of different salinity layers and are very sensitive to eutrophication effects. For example, Janßen et al. (2015) stated that the development of significant numbers of wind farms in an area with already poor oxygen conditions, can lead to anoxia, due to changes in the currents regime (mixing dilutions and current velocities) and accumulation of biomass. In particular, biofouling organisms such as blue mussel can increase oxygen consumption and may foster the occurrence of anoxia.

Again, this criterion, as reported for Baltic and North Seas, does not seem to be relevant to Macaronesia due to the particular hydrodynamics and oceanography of the archipelagos.

6 Analysis Descriptor 6: Sea-floor Integrity

Sea-floor integrity takes into consideration the major physical (hard *vs* soft bottoms), chemical (inorganic *vs* organic matter presence) and biological (macroalgae *vs* invertebrate communities) features of the sea bottom. These characteristics delineate the structure and functioning of marine ecosystems, especially for species and communities living on the sea floor (benthic ecosystems).

The construction of OWFs modifies the sea-floor integrity in diverse ways, which are mainly related to the configuration, dimensions and design of the wind turbine fixation structures.

Table 5

QD6 Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD6	Spatial extent and distribution of physical loss (permanent change) of the natural seabed	D6C1	Yes	narrower	needed further research	needed further research	needed further research
	Spatial extent and distribution of physical disturbance (including intertidal areas) pressures on the seabed.	D6C2	No				
	Spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions (e.g. through changes in species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), by physical disturbance.	D6C3	No				

6.1 D6C1- Spatial extent and distribution of physical loss (permanent change)

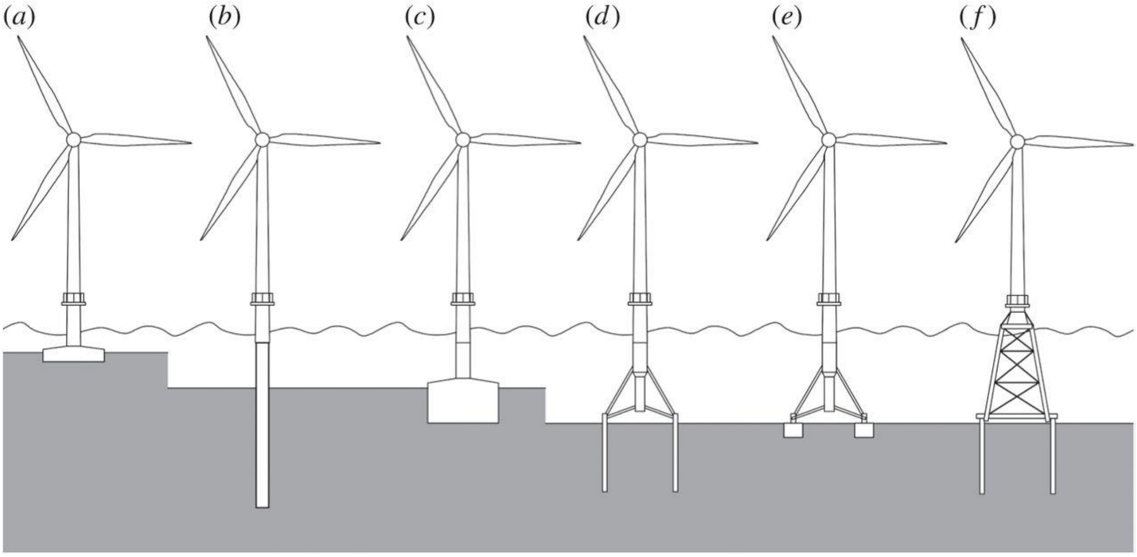

Figure 1 by Kallehave et al.,2015, (a) Gravity-based foundation (16%), (b) monopile foundation (74%), (c) caisson foundation (0%), (d) multipile foundation (5%), (e) multi caisson foundation (0%) and (f) jacket foundation (5%).

For the wind industry to survive, it is vital that costs are significantly reduced for future projects. One of the areas where costs can be reduced is in the support structure, where better design, cheaper fabrication and quicker installation can play a key role. Different support structures/foundations have different effects on physical loss and physical permanent change on the seabed. However, in most cases it can be accepted that physical loss of the seabed is minimal. Adequate selection of the seabed substrate (sand, gravel, etc.) for foundations can minimise impact and permanent change. Rocky substrates may require more complicated engineering solutions that can have a higher impact and potentially greater and more significant permanent changes. In the decommissioning, especially for monopile foundations, a process involve cutting, water jetting and/or explosives, can be expected, and this can have wider and possibly more significant impacts on the seabed (Topham & McMillan, 2017). At the end of life stage, there is little documented experience worldwide of OWF decommissioning and decommissioning processes, and this will require further applied research.

Secondly, due to the seabed morphology and depth gradients in Macaronesia, it is expected that a high degree of innovation with new types of foundations and anchoring solutions for floating base turbines will be required. The first floating wind turbine was installed in 2008 in Norway, and this type of design is still in development, with a new OWF with 5 floating wind turbines recently operational in Scottish waters. The impact on the seabed and permanent change needs further research. In addition, there is a high probability that permanent change of the sea floor can be treated as an insignificant criteria in Macaronesia, if new design of floating base turbines are implemented and the appropriate location/substrate selected.

6.2 D6C2 Spatial extent and distribution of physical disturbance pressures on the seabed

In OWFs constructed near-shore, it is possible to observe their impact on suspended sediments in shallow waters (Vanhellemont & Ruddick, 2014, Bailey et al., 2014, Bergström et al., 2014).). Turbid wakes of individual turbines are observed that are aligned with tidal currents, (measuring some 30 to 150m wide, and several km in length). The impact of these wakes is the related water turbidity due to the increase in suspended sediments, including the impact on sediment transport and sedimentation. This effect should be only considered with the soft substrate seabed and with OWF installed up to 20m depth. As such it is an unlikely impact due to the coastal morphology and sea floor characteristics in Macaronesia.

6.3 D6C3 Spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance

The main pressures here are related to physical loss due to permanent change of the seabed substrate or as consequence of the extraction of seabed substrate.

The surface area of the OWF foundations and related materials, such as submerged electric cables and other support structures, does not occupy a large extent on the sea floor. The challenges associated with the feasibility of future OWF relate to the cost reduction in the installation phase as well as during the operational phase. Therefore, in the future, foundation sizes are likely to decrease and structures will be more resilient to bad weather conditions. OWF foundations and scour protections on the seabed can lead to increased habitat complexity that affect certain fish species and communities positively (Langhamer, 2012; Bergström et al., 2013; Stenberg et al., 2015; van Hal et al., 2017). More in depth discussion on this is included under Quality descriptor 1 - Benthic habitats - criteria D6C5.

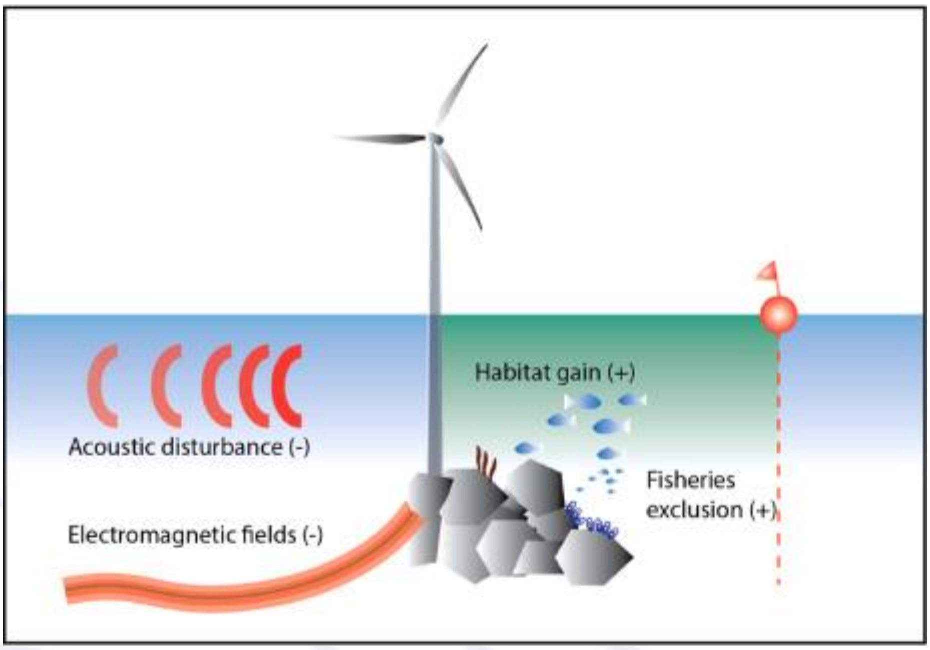

Figure 2 - Habitat gain and other effects related to marine wind turbine installation, Bergström et al. (2013).

7 Analysis Descriptor 7: Hydrographical Conditions

Offshore platforms and marine renewable energy installations as OWF are identified as one of the main pressures on hydrographical conditions.

"Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems" (EC DG ENV).

Hydrographical conditions are characterised by the physical parameters of seawater, which are temperature, salinity, depth, currents, waves, turbulence, turbidity (related to the load of suspended particulate matter). Modification of any hydrographical condition can have a significant effect on the marine ecosystems, including biomass production and the growth of plankton and fish species. In addition, modifying current regimes can affect larval dispersion and habitats for benthic and pelagic species. Additionally, changes of hydrographical conditions can affect exchanges between the sea and the atmosphere and between the various layers of water.

DC7 Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD7	Hydrographical changes to the seabed and water column (including intertidal areas).Spatial extent and distribution of permanent alteration of hydrographical conditions (e.g. changes in wave action, currents, salinity, temperature) to the seabed and water column, associated in particular with physical loss (7) of the natural seabed.	D7C1 — Secondary	Yes	Broader	No	Yes	Yes
	Spatial extent of each benthic habitat type adversely affected (physical and hydrographical characteristics and associated biological communities) due to permanent alteration of hydrographical conditions.	D7C2 — Secondary	No				

7.1 D7C1 Hydrographical changes to the seabed and water column

7.1.1 Currents

As the tidal, wind, storm currents flow past OWF foundation structures they generate a turbulent wake that contributes to a mixing of the stratification. This can lead to a doming of the thermocline and a subsequent transport of nutrients into the surface, mixed layer (Cazenave et al., 2016; Carpenter et al., 2016; Floeter et al. 2017). Turbulent wake depends on the drag coefficient and turbines foundation type. In theory, turbine foundations are smoots cylinders, but in practice, foundation are usually abundant with mussels & other biofuling organisms that increase roughness and, subsequently, raise the turbulent vertical mixing effect (Petersen & Malm 2006; Baeye & Fettweis, 2015). Pressure solutions can be delivered within the design of turbine foundations, but at this moment further research is needed to ascertain if this potential effect is relevant during operational phase of OWF in Macaronesia.

7.1.2 Salinity

The effect of OWF on salinity depends on the thermocline depth & upwelling effect. However, this can be omitted from consideration in Macaronesia, given the characteristic of its coasts and its oceanography.

7.1.3 Waves

Christensen (et al., 2013) considers the impact of offshore wind farms on the wave conditions. When the waves meet OFMs the wave field can be altered due to three significant processes that have to be considered. These are; A) the dissipation of wave energy due to drag resistance, B) reflection/diffraction of waves around the structure, and, C) the effect of a changed wind field inside and on the lee side of the offshore wind farm. Christensen (et al., 2013) developed a study using a hydrodynamical model MIKE 2. Modelling of waves using 3rd generation numerical spectral wind wave models from known wind fields and bathymetries has gone from a “state of the art” to the “state of practice” and now provides quite accurate results. Dissipation of the wave energy due surface friction and vortex shedding is negligible.

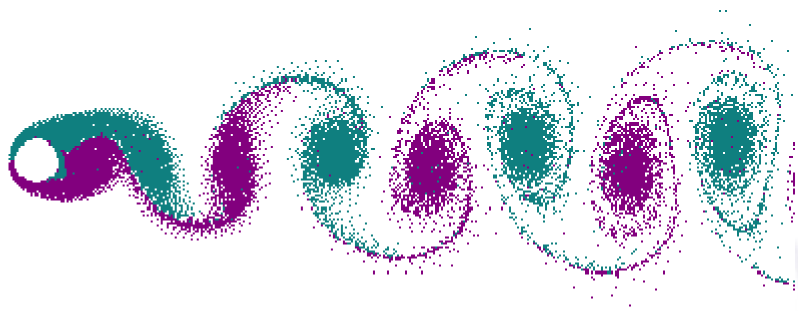

Figure 3 - vortex shedding, Christensen et al., 2013

From three numbered OWF effects, results marked the reflection/diffraction of waves as most significant one: effect on the wave height upwind of the wind farm up to 2 to 3%. For moderate wind speed, the local reduction of wave height, downwind, comes 1/3 from reflection/diffraction and 2/3 from the reduced wind shear (gradient of pressure). In the model results, downwind - 3 times the extent of the OWF, the effect of reduced wind shear controls the major part of the wave height reduction (around 5%).

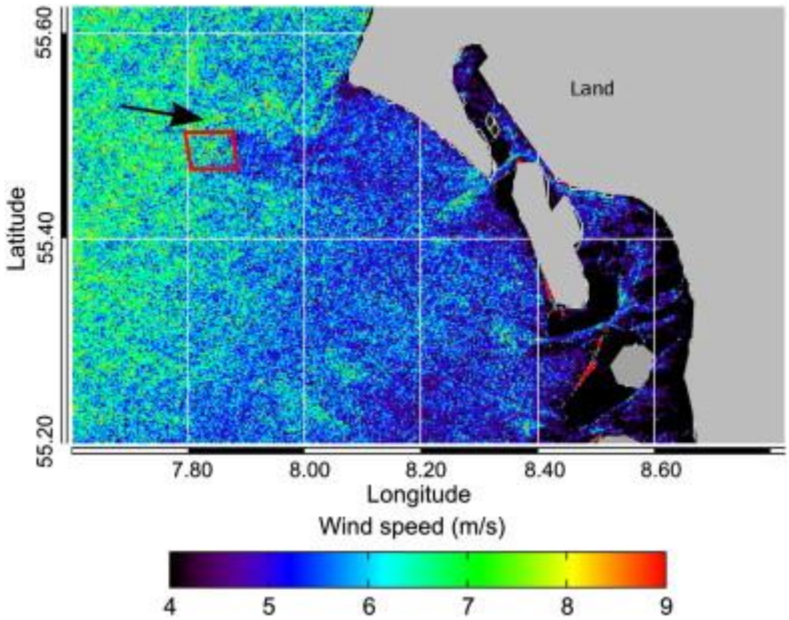

Figure 4 - reduced wind speed on the lee side

For high wind speeds the most important process is the reduced wind speed inside and on the lee side of the OWF. The OWF had little influence on the wave period (max 1%). Further research is needed, for this effect to be identified as relevant to the operational phase of OWF in Macaronesia.

7.1.4 Turbidity

In the construction phase, in development of the OWF, gravity foundations involve greater impact from sediment dispersal, due to dredging operations. Elevated turbidity may harm sensitive organisms, such as juvenile fish (Auld & Schubel 1978, Lake & Hinch 1999, Partridge & Michael 2010), but expected impact is low to moderate as organisms in the sand seabed are tolerant to turbidity (Bergström et al., 2014). Li and collaborators (2014) using remote sensing SAR and Christie & Moulinec (2012) using hydrodynamic and morphological modelling techniques, identify large turbid wakes downstream of individual turbines, but only for OWF installed at shallow depth.

7.1.5 Monitoring

There are a number of difficulties in the monitoring and sampling information on the dynamics of the sea (EC-DG Environment). Therefore, large data sets are required to observe and detect changes in the hydrographic conditions as temperature, currents regime, waves and turbidity. At present data are provided by in situ measurements and satellite observation. Parameters data can be built at different scales with the help of 2D/3D models (Christensen et al., 2013) which are developed by “operational oceanography” programmes, and compared with results sampled in situ and remotely. If hydrographical changes impact on wave and current dynamics caused by potential OWF are found to be significant, engineering solutions will be needed to reduce pressures, and to mitigate impact and monitor/model current status.

8 Analysis of Descriptor 8 - Concentrations of contaminants

Contaminants are defined in the European legislation as:

"substances (i.e. chemical elements and compounds) or groups of substances that are toxic, persistent and liable to bio-accumulate and other substances or groups of substances which give rise to an equivalent level of concern" (Water Framework Directive, Article 2(29)).

Contaminants can arise from numerous anthropogenic sources such as land-based industrial activity, pollution by ships, atmospheric deposition, oil, gas and mineral exploration and exploitation and riverine inputs. With this study we want to see if there are current scientific or technical reports that identify any increase of the contaminants in water, biota or sediment due to the OWF construction, decommissioning or operating phase.

Table 6

DC8 Concentrations of contaminants are at levels not giving rise to pollution effects							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD8	Concentrations of contaminants (ubiquitous persistent, bioaccumulative and toxic substances - Article 8a(1)(a) of Directive 2008/105/EC) do not exceed the established (WFD) threshold values in water, sediment or biota.	D8C1	No				
	The health of species and the condition of habitats (such as their species composition and relative abundance at locations of chronic pollution) are not adversely affected due to contaminants including cumulative and synergetic effects.	D8C2 — Secondary	No				
	The spatial extent and duration of significant acute pollution events (Discharging oil and noxious liquid substances - MARPOL 73/78Article 2(2) of	D8C3	No				

	Directive 2005/35/EC) are minimised.						
	The adverse effects of significant acute pollution events on the health of species and on the condition of habitats (such as their species composition and relative abundance)	D8C4	No				

8.1 D8C1 Concentrations of contaminants

Zaborska and collaborators in (2017) studied if construction of OWF can re-introduce deposited contaminants in seabed back to the water column. This possibility was identified in the Baltic Sea, and was highly influenced by riverine inputs, and with significant level of anthropogenic substances, such as heavy metals, already deposited in the seabed sediment. This is not a case in Macaronesia and this criteria and descriptor for now can be excluded from analyses. Apart from a study delivered by Zaborska et al. in 2017, no further scientific publication or technical reports have been found dealing with this issue.

D8C3 The spatial extent and duration of significant acute pollution events

During construction phase and during the maintenance operations the risk of acute pollution (oil spills) due to an accident or collision is increased. Some authors mention that OWF increases oil spill risk, resulting from tanker collisions with wind farms (Gee, 2010). In both cases, applying the required level of safety and security decreases these risks. For D8C4, as for D8C3 there are no available reports, so further research on statistics of oil spills in the area of OWF is necessary to identify if this is a real threat.

9 Analysis Descriptor 9 - Contaminants in fish and other seafood

Table 7

QD9 Contaminants in fish and other seafood for human consumption do not exceed levels established by Union legislation or other relevant standards							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD9	The level of contaminants in edible tissues (muscle, liver, roe, flesh or other soft parts, as appropriate) of seafood (including fish, crustaceans, mollusks, echinoderms, seaweeds and other marine plants) caught or harvested in the wild (excluding fin-fish from mariculture) does not exceed Regulation (EC) No 1881/2006	D9C1	Need further research	Need further research	Need further research	Need further research	Need further research

Within the review, no technical reports or scientific publications have been found concerning OWF and levels of contaminant in fish and seafood.

As a precautionary measure, it is recommended to determine baseline levels of contaminants in fish and other seafood coming from coastal and Macaronesian marine ecosystems for future comparison with those coming from, or captured near, a OWF operational site located in Macaronesia.

10 Analysis Descriptor 10 - Marine litter

Marine litter is a global concern, affecting all the oceans of the world. Every year, millions of tonnes of litter end up in the ocean worldwide, posing environmental, economic, health and aesthetic problems (WSPA, 2014; UNEP & GRID-Arendal, 2016; Lusher et al., 2017).

Poor practices of solid waste management, waste water (including storm water) collection and treatment, lack of infrastructure and awareness of the public at large about the consequences of their actions aggravate substantially the situation.

Table 8

QD10 Properties and quantities of marine litter do not cause harm to the coastal and marine environment							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD10	The composition, amount and spatial distribution of litter (excluding micro-litter, classified in the following categories: artificial polymer materials, rubber, cloth/textile, paper/cardboard, processed/worked wood, metal, glass/ceramics, chemicals, undefined, and food waste) on the coastline, in the surface layer of the water column, and on the seabed, are at levels that do not cause harm to the coastal and marine environment.	D10C1	No				
	The composition, amount and spatial distribution of micro-litter (particles < 5mm) on the coastline, in the surface layer of the water column, and in seabed sediment, are at levels that do not cause harm to the coastal and marine environment.	D10C2	No				

	The amount of litter and micro-litter classified in the categories 'artificial polymer materials' and 'other' ingested by marine animals (birds, mammals, reptiles, fish or invertebrates.) is at a level that does not adversely affect the health of the species concerned.	D10C3 — Secondary					
	The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.	D10C4 — Secondary					

10.1 D10C1 Marine litter

Within the review no technical reports or scientific publications have been uncovered concerning marine litter and OWF in either the construction or the operational phases. Decommissioning processes after the life cycle of the OWF can be a possible source of marine litter. As the first offshore wind energy project to be decommissioned took place in 2016, until now there are no reports that can confirm this as a real threat. In the study on sustainable decommissioning, delivered by Topham & McMillan (2017) difficulties in foundations decommissioning for the monopile and gravity turbine foundations I s mentioned. Decommissioning monopile foundations includes diamond wire cutting or water jetting. Both methods include operations that put safety personal in risk and provide environmental impact due additional exaction in the seafloor. Notably, gravity turbine foundations sometimes leave an artificial reef, if a structure is provided for new habitats to attract pelagic and benthic species. In both cases debris produced with the engineering operations of cutting, water jetting or even explosions need to be removed. This criterion should be investigated further in future OWF decommissioning operations.

10.2 D10C2 Micro- litter

Presently, there are no technical reports or scientific publication that identify OWF as a source of microplastics, but there are research studies that investigate this possibility. Wang et al. (2018) assessed the microplastic contamination, composition and distribution characteristics in offshore wind farms situated in the shallow sea area (max 8m depth). That study concluded that hydrodynamics - particularly shear stress, in the area of the OWF, can reduce plastic abundance in the water and sediment. The presence of a wind farm can increase the bed shear stress (including 5m depth), leading to instability and bed sediment transport and thereby causing the microplastics adhered to the sediments to be washed away more easily. This may explain the lower sediment microplastic abundance found within the wind farm compared with outside the wind farm.

Further research should be delivered if there is a significant impact on sediment and the water column and surface, during the construction phase.

11 Analysis Descriptor 11 - Energy incl. Underwater Noise

Noise pollution has attracted much attention as it has the potential to displace animals, interfere with normal behavior and, at very high levels, cause physical damage. Underwater noise, whether from natural or anthropogenic sources, may interfere with the way marine life receives and send acoustic signals. Maritime shipping is increasingly recognised as a significant and pervasive pollutant with the potential to impact on marine ecosystems on a global scale (Williams et al., 2015); seismic surveys have a much greater local impact than shipping, especially on fish and invertebrates (Carroll et al., 2017) and on marine mammals (Erbe et al., 2016). Other human activities, such as military activity, offshore construction, anti-predator devices, and recreational boats may also be significant local or regional sources of underwater noise. Marine renewable energy devices may produce lower noise levels than many other anthropogenic sources, but have the potential to cause long-term exposure to sessile marine organisms (Gill, 2005).

Table 9

QD11 Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD11	The spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect populations of marine animals.	D11C1	yes	broader	yes	yes	yes
	The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals.	D11C2	No				

11.1 D11C1 Anthropogenic impulsive sound

Impulsive noise coming from OWF has three phases: the short-term potential impact during pre-construction; the short-term intensive impact during construction; and the physiological and/or masking effects that may occur over a long period while the wind farm is in operation (Kikuchi, 2010). During the pre-construction phase there is a risk to marine mammals, sea turtles and fish of collision and disturbance from vessel movements associated with surveying and installation. During the construction phase, noise and vibration from pile driving and other works may affect the animals over a large area (Thomsen et al., 2006; Nedwall et al., 2007; Diedrichs et al., 2008, Dolman & Simmonds 2010; EC, 2011). The noise impact on marine mammals is more severe during the construction of wind farms than during their operation (Madsen et al., 2006). During operation, underwater sound levels are unlikely to reach dangerous levels or mask acoustic communication of marine mammals (Tougaard et al., 2009) and this impact in most cases is considered to be of minor importance to the marine environment (Westerberg & Lagenfelt, 2008, Petersen & Malm, 2006, Wilhelmsson et al., 2010).

The high scores associated with extreme noise from pile-driving, which is mainly used in the deployment of OWF based on monopiles or jacket foundations, cause significant avoidance behaviour in marine mammals (Richardson et al., 1995; Carstensen et al., 2006; Tougaard et al., 2008, Bailey et al., 2010, Brandt et al., 2011, Dähne et al., 2013). High sound levels can damage the inner ear sensory cells, produce hearing loss, alter the behavior of fishes and can even cause mortality (especially at larval stage) in fish (Popper et al., 2003; Nedwell & Howell 2004; Popper & Hastings, 2009). A considerably lower acoustic impact can be expected for OWF based on gravity foundations, which do not involve pile-driving (Hammar et al., 2008).

Construction often includes an array of activities, including profiling, shipping, pile-driving, trenching and dredging (Nedwell & Howell 2004, Bolle et al., 2012 & Bolle et al., 2016). Increased vessel activities during exploration and construction operations may produce a complete, but temporary, displacement from an area, but if the animals all return to the area shortly afterwards with no hearing impairment, the actual impact on the population may be small (Madsen et al., 2006). During the planning and construction period, avoiding biologically sensitive periods can significantly reduce animal disturbance pressure (Hammar et al., 2014). Pressure mitigation can be obtained using acoustic (bubble) curtains that attenuate noise from offshore wind farm construction and reduce temporary habitat loss (Würsig et al., 2000; Caltrans, 2009; Lucke et al. 2011; Dähne et al., 2017).

Figure 5 - Air bubble curtain around offshore platform. From http://www.hydrotechnik-luebeck.de

During the operational phase, vibration caused in the turbine and vibrations transmitted to the sea floor should be considered. Studies delivered by Nedwell and collaborators (2003), and Andersson (2011) define this acoustic disturbance of the sea floor as highly local and of minor importance. To advance mitigation, avoid impacts and improve survey and knowledge, the EU proposed to the UNEP in 2008, noise databases listing the origins of man-made sounds (including the OWF) within the resolution of Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and other Biota (Kikuchi, 2010). Setting up a register of the occurrence of impulsive sounds is a first step to establishing current level and trends on anthropogenic sound pressure, including most important sound sources, including military activities, geological surveys, etc. (Dekeling et al., 2014). This resolution was adopted 2014, but development of noise databases is only included as an encouragement to signing parties “the compilation of a reference signature database, to be made publicly available, to assist in identifying the source of potentially damaging sounds”. This resulted in various data initiatives, as ICES Impulsive noise events registry, supported by OSPAR and HELCOM regional sea conventions that provide spatial data base for the North Sea and Baltic, including the noise disturbance from the wind farms. Avoidance of animals for OWF can be compared with avoidance of harbours, and include possibly habituation over time (Teilmann & Carstensen, 2012), but this differs among species (Popper & Hastings 2009).

Finally, the main impacts within the impulsive sound are the short-term potential impact during pre-construction; the short-term intensive impact during construction; and turbine structural vibrations, that can be spread into to sea and seafloor, that may occur over a long period while the wind farm is in operation (Nedwell & Howell, 2004; Kikuchi, 2010). The pressure extent vary depending local conditions, where stronger impacts might be expected in pristine areas compared to areas where ambient noise is already high (Scheidat et al., 2011). Cumulative effects should be also considered (Slabbekoorn et al., 2010), using the operative noise registries. Three type of mitigation are possible:

a) reduction of noise on the source (using the gravity foundation, avoiding the monopile after Koschinski & Lüdemann, 2014 study);

b) to reduce the sound energy propagated as using bubble curtains (Würsig et al., 2000; Caltrans, 2009; Lucke et al., 2011; Dähne et al., 2017); and

c) to reduce impact preventing animals from being located in the vicinity of the sound source, by scheduling the pre-construction and construction in adequate time, avoiding biologically sensitive periods (Hammar et al., 2014).

11.1.1 Monitoring

The MSFD Technical Subgroup on Noise concludes that for quality descriptor 11, impulsive sound monitoring requires development of noise registry, combining use of measurements with models including sound maps, as the best way to ascertain levels and trends of ambient noise in the relevant frequency bands.

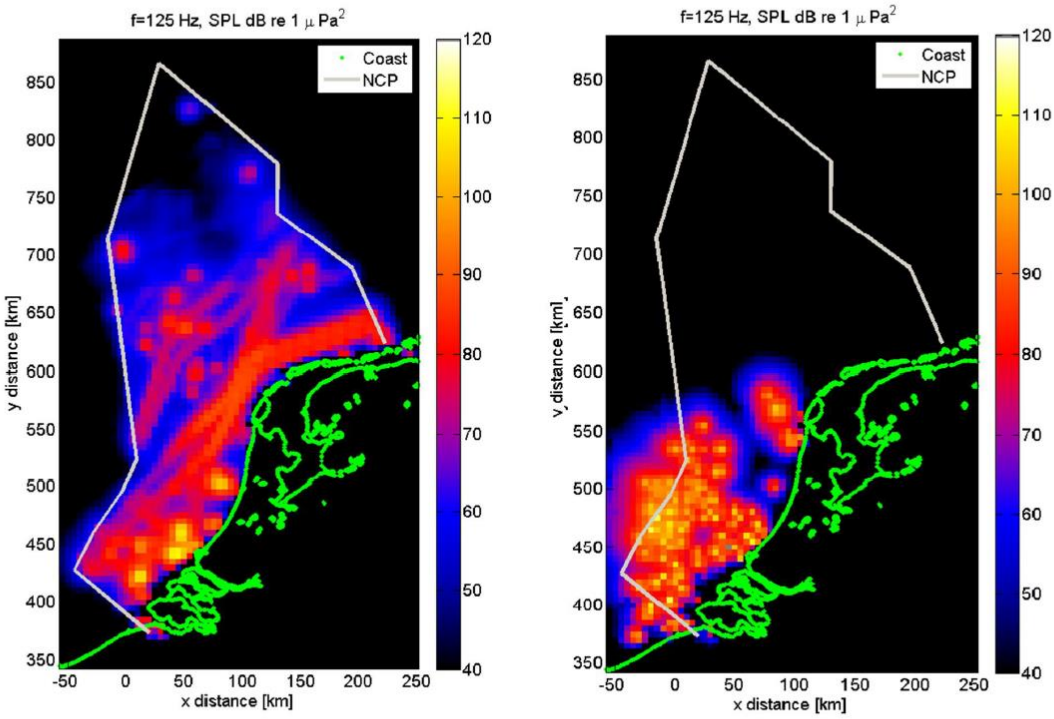

Figure 6 - Annually averaged noise predictions for the Dutch North Sea, delivered by University of Leiden, included in the JRC guidance on monitoring ofn underwater noise (2014)

11.2 D11C2 Anthropogenic continuous low frequency sound

Underwater noise from the operating turbines is generated by the machinery in the nacelle and is transmitted through the tower to the foundation, from which it is radiated into the water (Tougaard et al., 2008). Under normal conditions, the noise is of low intensity by any standard (Madsen et al., 2005), with energy concentrated at low frequencies (below a few kilohertz). Under favorable conditions (low background noise, low transmission loss), the sound may be audible to seals, toothed whales and fish at distances up to some kilometres from the turbines. Nevertheless, due to the low intensity and low frequencies of that type of noise, the impact on marine mammals is considered marginal (Tougaard et al., 2008).

Koschinski et al. (2003) introduced high-frequency artifacts, simulating operational 2MW turbine, into the signal and that the porpoises and seals may have been responding to these artifacts rather than the low-frequency wind turbine noise intended for playback and study showed that the responses, if any, occurred within a 60m to 200m perimeter around the sound source, reinforcing the conclusion that the impact zone for turbine noise is small for both porpoises and seals. Elaborate investigations on the propagation of low-level sound from operating wind turbines may therefore not be justified, if behavioural studies confirm that the range of received levels more than about 100m from the turbine do not alter the behaviour of the marine mammal species.

Finally, the transmission of electricity through cables within the wind farm and to shore can create electromagnetic fields that may also interfere with short- and long-range orientation systems. Disturbance effects could be particularly pronounced in elasmobranchs (sharks and rays) that are highly sensitive to magnetic fields and use electromagnetic signals in detecting prey. Westerberg & Begout-Anras in 2000, Westerberg & Lagenfelt in 2008 and more recently, Gill et al. in 2012 also delivered empirical studies on the European eels, warning about the possibility that created electromagnetic fields can disturb species migration patterns. However, except for a few metres around cables and other devices, field strength is well below that of the earth's geomagnetic field. Studies so far have judged the impact to be small although available results are not entirely conclusive (Petersen & Malm, 2006; Meissner & Sordyl, 2006; EC 2011; Gill et al., 2012). The extent of the electromagnetic field can be mitigated by adequate cable design (Bergström et al., 2014) and the appropriate cable deployment to avoid marine areas with sensitive species.

Analyses of GES Descriptors/Criteria related to the Biodiversity

This section considers the descriptors linked to the relevant ecosystem elements: species groups of birds, mammals, reptiles, fish and cephalopods (Descriptor 1), pelagic habitats (Descriptor 1), benthic habitats (Descriptors 1 and 6) and ecosystems, including food webs.

Langhammer and collaborators in a recent paper (2018) state that we do not have a clear picture on the biodiversity impact of OWF. They propose the control of site impact, by focusing on dominating specie(s). For example, the study of viviparous blenny / European eelpout (*Zoarces viviparous*) has been suggested as prime candidate for monitoring of anthropogenic activities, indicating modifications within Good Environmental Status in the Baltic and North Sea (Sturve et al., 2005; Hedman et al., 2011).

12 QD1 Species (birds, mammals, reptiles, fish & cephalopods)

Table 10

QD1 Species groups of birds, mammals, reptiles, fish and cephalopods (relating to Descriptor 1)							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD1	The mortality rate of birds, mammals, reptiles and non-commercially-exploited species of fish and cephalopods from incidental by-catch is below levels which threaten the species, such that its long-term viability is ensured.	D1C1	Yes (birds)	equal	Yes	yes	yes

	The population abundance of the species is not adversely affected due to anthropogenic pressures, such that its long-term viability is ensured. Including mammals and reptiles listed in Annex II to Directive 92/43/EEC, but also other Annexes to Directive 92/43/EEC, Directive 2009/147/EC or through Regulation (EU) No 1380/2013, and RSC's	D1C2	No				
	The population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity, and survival rates) of the species are indicative of a healthy population which is not adversely affected due to anthropogenic pressures. Primary for commercially-exploited fish and cephalopods and secondary for other species	D1C3	Need further research				
	The species distributional range and, where relevant, pattern is in line with prevailing physiographic, geographic and climatic conditions. Primary for species covered by Annexes II, IV or V to Directive 92/43/EEC and secondary for other species.	D1C4	Yes	Broader			
	The habitat for the species has the necessary extent and condition to support the different stages in the life history of the species. Primary for species covered by Annexes II, IV and V to	D1C5	No				

	Directive 92/43/EEC and secondary for other species						

12.1 D1C1 The mortality rate

Pollution and fisheries by-catch are identified as the most important anthropogenic threats to marine mammals (Hårding & Härkönen, 1999, Härkönen & Isakson, 2010) and marine birds. Evidence to date indicates that appropriately sited and well-designed wind energy developments are generally not a threat to biodiversity. Firstly, there is a need to put impacts into a population level context and to determine whether they are biologically significant or not (Bailey et al., 2014). However, there may be occasions where individual plans or projects can cause damage to protected wildlife and nature areas. The analysed studies suggest that various species of birds and marine animals may be particularly vulnerable. The type and degree of impact is very much dependent upon a range of factors, such as location and the type of species present. Wind farm projects that avoid, or are located away from, areas of importance for wildlife, generally, dare not likely to have a major impact on biodiversity. However, potential impacts must be examined on a case by case basis (EC, 2011).

In the case of OWF projects, an obvious mitigation measure is to adjust the location of the wind farm away from areas where it can cause conflicts with species and habitat types. But mitigation measures can also involve modifications to the size, design and configuration of the wind farms or the construction of turbines and associated infrastructures. And they can take the form of temporal adjustments during the construction and operational phases.

OWFs may increase mortality of seabirds through collisions with turbines. They may create barriers to movement of birds and may displace birds from foraging habitat (Drewitt & Langston, 2006; Masden et al., 2010; Dierschke et al., 2016). Seabird species with greatest risk of collision mortality are those that spend a high proportion of time flying at the height of turbine blades (for the 2 MW turbines, a tower height is typically 80m with a rotor diameter of 90m, resulting heights between 35m and 125m (Johnston et al., 2014). In any event, studies of collisions caused by terrestrial wind turbines have recorded relatively low levels of bird mortality (Winkelman, 1992a&b; Painter et al., 1999; Erickson et al., 2001), due the fact that studied wind farms were located away from large concentrations or birds and flying/migrational patterns. Collision risk depends on a range of factors related to bird species (collision risk varies for each particular species), numbers and behaviour, weather conditions and the nature of the wind farm itself, including the use of lighting (Dierschke et al., 2016).

The aviation and shipping warning lights on turbines can attract and disorient birds, and as a measure to mitigate this impact it is possible to use a minimum number of intermittent flashing white lights of lowest effective intensity (Hüppop et al., 2006). Proper location of OWF based on the study on species can avoid most of the impacts, avoiding:

- high densities of wintering or migratory species;
- areas with a high level of raptor activity;
- areas for breeding, wintering or migrating populations of less abundant-conservation concern species (Dierschke et al., 2016).

BACI (Before-After-Control-Impact) monitoring using a radar to monitor bird movement is an effective technique for offshore bird collision impact (Christensen et al., 2004; Kahlert et al., 2004a&b; Pettersson, 2005). Other mitigation techniques proposed by (Dierschke et al., 2016) include:

- Avoidance of key areas of conservation importance and sensitivity are avoided;
- Grouping turbines to avoid perpendicular alignment to the main bird flight pathways;
- Provision of corridors between clusters; and
- Increasing the visibility of rotor blades.

12.2 D1C2 population abundance of the species is not adversely affected due to anthropogenic pressures

Evidence to date indicates that wind farms that are located away from areas harbouring concentrations of wild animals or areas that are important for wildlife have relatively low influence or no influence on population abundance (EC, 2011).

12.3 D1C3 The population demographic characteristics - body size or age class structure, sex ratio, fecundity, and survival rates

This study revealed no technical reports or scientific publications relating to OWF regarding species population, demographic characteristics.

12.4 D1C4 The species distributional range and pattern

Wind farms, especially large establishments with tens of individual wind turbines, may force birds, mammals and turtles to change direction, both during migrations and, more locally, during regular foraging activities. This is a barrier effect. Additionally, disturbance can lead to displacement and exclusion, and hence loss of habitat use. This risk may be relevant for birds and marine mammals. The species may be displaced from areas within and surrounding wind farms due to visual, noise and vibration impacts. Disturbance may also arise from increased human activity during construction work and maintenance visits. The scale and degree of disturbance determines the significance of the impact, as does the availability and quality of other suitable habitats nearby that can accommodate the displaced animals (EC, 2011). In addition, marine species can be attracted to the OWF area, due the reef effect (the creation of new habitats).

<u>Seabirds</u>
The extent to which seabirds are displaced from, or attracted to OWF is uncertain, but the rapid development of the OWF facilities can conflict with seabird conservation (Dierschke et al., 2016). Additionally, seabird conservation could constrain future development of OWF (Madsen et al., 2015), increasing seabird mortality and displacement of birds from their foraging habitat (Drewitt & Langston, 2006; Masden et al., 2010). Displacement of birds can be due the noise and vibrations, mainly in the construction phase and this issue is analysed within Quality Descriptor 11, (both criteria D11C1 and D11C2). The disturbance that is based on the visual impact and barrier effect impact, including the mitigation are described in D1C1, which recommends a BACI monitoring strategy to determine impact intensity. Studies report incremental growth in numbers of some bird species due the reef effect. It is likely that they are attracted by mussels or fish prey in the new habitat (Drewitt & Langston, 2006; Raoux et al., 2018).

<u>Mammals, reptiles, fish & cephalopods</u>
Displacement of marine animals seems to be due to the noise and vibrations, mainly in the construction phase, and this issue is analysed within Quality Descriptor 11, both

criteria (D11C1 and D11C2). The barrier effect is discussed within D1C1 and it is concluded that the evidence to date indicates that appropriately-sited and well-designed wind energy developments are generally not a threat to biodiversity (Bailey et al., 2014).

12.5 D1C5 The habitat has the necessary extent and condition to support the different stages in the life history of the species

The further criteria analysed (under D1C6 and D6C5) are referred to under pelagic and benthic habitats (D1C5).

13 QD1 Pelagic habitats

Table 11

QD1 Pelagic habitats (relating to Descriptor 1)							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD1	The condition of the habitat type, including its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), is not adversely affected due to anthropogenic pressures.	D1C6	Further research recommended				

13.1 D1C6 The condition of the pelagic habitat

In the European context, it is not mandatory to have investigation or monitoring of the potential effects of OWFs on the pelagic ecosystem (although, for example, it is part of the German EIA approval procedure for installing OWF). Only a limited number of studies have analysed OWF effects on the pelagic ecosystem, and even fewer include field measurements (Floeter et al., 2017).

The observations revealed that pelagic fish (mackerel) have the highest abundances within 100m of underwater construction sites (Schröder et al., 2013). Floeter and collaborators (2017) did an extensive empirical study, applying in situ sampling and modelling, for the current regime, water column stratification, phytoplankton and pelagic fish distribution, in order to define OWF effects on the pelagic habitats. They tried to separate ambient hydrography from the currents regime affected by the OWP. These included, effects on the water column stratification due vertical mixing, the upwelling effect and the increase of nutrients and primary production in the superficial layers, zooplankton and fish density and distribution.

In situ measures of salinity and turbidity, combined with remote sensing (Li et al., 2014; Vanhellemont & Ruddick, 2014), and modelling (Lass et al., 2008; Rennau et al., 2012; Cazenave et al., 2016), demonstrated that upwelling areas for each turbine can be up to 1 km in extent. Increased primary production occurds in this area, with enhanced phytoplankton biomass, increasing trophic levels and more attractive habitat for pelagic fish. Empirical (Floeter et al., 2017) and conceptual studies (Van der Molen et al., 2014) on primary production provide opposite results, indicating the need for more research in this area. Again, the highest pelagic fish abundances are found close to the turbine foundations, as observed by Schröder et al. (2013) and Krägefsky (2014). In contrast, the study performed by Floeter et al. (2017) the hydroacoustic instruments under the vessel could not detected this and it should be noted that the results obtained in this study are difficult to fully separate regarding anthropogenic impacts and natural variability.

Presently, there are no OWFs in Macaronesia, and it is easy to define baseline or control values (no impact areas). With potential future development of OWFs, multi-disciplinary quantification of the wind wave effect should be performed at the regional ecosystem scale, with a focus on the cumulative effects of OWF clusters and on the trophic transfer of any increase in production, that can have impact on pelagic habitat.

14 QD1 & QD6 Benthic habitats

Table 12

QD1& QD6 Benthic habitats (relating to Descriptors 1 and 6)							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD1&QD6	The extent of loss of the habitat type, resulting from anthropogenic pressures, does not exceed a specified proportion of the natural extent of the habitat type in the assessment area.	D6C4	No				
	The extent of adverse effects from anthropogenic pressures on the condition of the habitat type, including alteration to its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), does not exceed a specified proportion of the natural extent of the habitat type in the assessment area.	D6C5	Yes				

14.1 D6C5 Habitat extension

OWF's in most of the cases act as a new type of habitat with a higher biodiversity of benthic organisms, possibly increasing the use of the area by the benthos, fish, marine mammals and some bird species and a decreasing use by several other bird species (Lindeboom et al., 2011). Turbine submerged constructions are colonised by several marine species resulting in an additional source of food for higher trophic levels (Bergström et al., 2013). This effect, generally known as the "reef effect". Expected habitat gain is considered as one of the most important effect on the marine environment generated by the construction of offshore wind farms (Peterson & Malm, 2006; Langhamer, 2012; De Mesel et al., 2015). The reef effect commences with colonisation and aggregation of species close to the foundations, (e.g. Wilhelmsson et al 2006a; Maar et al., 2009), resulting in increased species abundances close to OWF foundations (Wilhelmsson et al., 2006, Wilhelmsson & Malm, 2008; Maar et al., 2009; Andersson & Öhman, 2010; Reubens et al., 2011; Bergström et al., 2013; Reubens et al., 2013).

Studies in the Baltic States show an increase in biomass by enlarging habitats from benthos layers into the pelagic column. This can increase oxygen consumption through respiration of living biomass and especially through degradation of dead biomass, and may lead to local anoxia (Janßen et al., 2015). This is highly relevant in enclosed waters such as the Baltic Sea, whereas in the Macaronesia context the anoxia effect can be discounted.

15 QD1&QD4 Ecosystems, including food webs

QD1&QD4 Ecosystems, including food webs (relating to Descriptors 1 and 4)							
QD	**Criteria (element)**	**CODE Criteria**	**Env. Impact**	**Env. impact spatial extent**	**MA pressure solutions**	**Impact mitigation measures**	**Monitoring method**
QD1&QD4	The diversity (species composition and their relative abundance) of the trophic guild is not adversely affected due to anthropogenic pressures.	D4C1	Further research needed				
	The balance of total abundance between the trophic guilds is not adversely affected due to anthropogenic pressures.	D4C2	Further research needed				
	The size distribution of individuals across the trophic guild is not adversely affected due to anthropogenic pressures.	D4C3 — Secondary	Further research needed				
	Productivity of the trophic guild is not adversely affected due to anthropogenic pressures.	D4C4 — Secondary	Further research needed				

15.1 D4C1, D4C2, D4C3, D4C4

In terms of impact the anthropogenic disturbances of the OWF will be reflected as modifications of the pelagic and benthic habitat. There will be direct disturbance on the species distribution, as species will be scared away by the OWF or attracted by the reef effect (Raoux et al.., 2017) Studies showed that a number of the ecosystem processes and properties are sensitive to changes generated by OWF installations (Burkhard et al., 2009), and can alter food webs. Accumulation of identified pressure/impacts in this study can lead to the impact on the specific food web guild, resulting from mortality (Winkelman 1992a&b; Painter et al., 1999; Erickson et al., 2001; Johnston et al., 2014), potential demographic modifications, species distribution range (Drewitt and Langston, 2006; Masden et al., 2010, Dierschke et al., 2016), and the effect on pelagic and benthic habitat (Schröder et al., 2013; Krägefsky, 2014; Floeter et al., 2017). Food web guild increment/decrement, could have a significant impact on ecosystem, and these relationships need to be further researched, especially with empirical studies that can identify OWF impacts expected in the biogeographic conditions of Macaronesia.

As a general recommendation, baseline studies of the structure and composition of major coastal ecosystems in the Macaronesian archipelagos are much needed to obtain robust data for the different parameters associated with GES criteria. The results obtained in these baseline studies will allow determination of the reference levels of species populations, habitat distribution patterns and ecosystem health before the potential deployment of OWFs in the Macaronesia region.

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