Supplementary materials: An overview on the required monitoring for offshore wind energy based on the "Guide to an offshore wind farm" by BVG Associates Limited (2019).

The Crown Estate and the Offshore Renewable Energy Catapult produced a report "Guide to an offshore wind farm" in 2019 for BVG Associates Limited [1]. In the report, monitoring requirements for entire OWF value chain, from siting to decommissioning, are covered. Although the information is still lack of details, it provides a good overview on the state-of-the-art on the monitoring requirement for OWF sectors. The Tables S1-S3 are produced based on the information collected from this report.

Table S1. An overview on required environmental monitoring activities

Monitoring activity	**Purposes**	**Sampling method**	**Sampling locations**	**What to measure**
Benthic environmental surveys	To categorise areas of similar environmental conditions to inform habitat and species impact studies.	Grab & sampling, epi-benthic beam trawling and drop down video (DDV).	Be able to produce the most effective broad-scale categorisation	Species living on the sea bed and in sediment
Fish and shellfish surveys	To identify species presenting in the farm site and surrounding areas, to inform impact analysis and reporting.	Beam trawls, otter trawls , lobster pots, gill nets, plankton nets or local fishing vessels	The farm site and surrounding areas	Species in the area, spawning
Ornithological environmental surveys	To establish the presence and behaviour of birds within the farm and surrounding areas for assessing risks to birds (collision with turbines, disturbance and displacement, and habitat loss)	Boat-based/digital aerial surveys, GPS tracking, radar and coastal vantage point (VP) surveys, min. two years	Farm and surrounding area	Annual cycle of bird abundance & distribution behaviour (e.g. flight height)
Marine mammal environmental surveys	To establish seasonal and inter-annual changes of marine mammals and assess OWF impacts on the mammals (incl. potential disturbance/ displacement, physical and auditory injury during pile driving, and habitat loss	Visual surveys, static and towed acoustic monitoring, tagging of individuals with satellite transmitters and remotely controlled video monitoring, monthly sampling, min. 2yr.	Within the wind farm boundary and surrounding areas.	mammals the diversity, abundance, distribution and behaviour of cetaceans (including porpoises, dolphins and whales) and seals
Human impact studies	To assess OWF impact on the community	Visual assessments, socio-economic study	Coastal area near the wind farm.	Photomontages, noise level, fisheries and archaeology, changes in employment, transportation, recreation etc.

Table S2. An overview on required metocean monitoring activities, geological and hydrographical surveys

Monitoring activity	**Sampling locations**	**Purpose**	**Sampling method**	**What to measure**
Resource and metocean assessment	The proposed wind farm	To provide metocean data for estimating future energy production, and to fully describe the likely operating conditions, incl. extreme wind and wave climate.	Met-mast, metocean buoys, (floating) lidar, weather models to inform turbulence and horizontal wind gradients in the site	Wind profile, surface meteo-variables, waves and tides for long-term (> 15 years).
Geophysical surveys	Along transects across zones within the proposed wind farm site and cable routes.	To establish sea floor bathymetry, features, water depth and soil stratigraphy, hazardous and risky areas on the seafloor; to aid the design and implementation of the benthic/geotechnical surveys, site layout design.	Seismic methods, echo sounding and magnetometry; acoustic seismic profiling methods and high resolution digital surveys.	bathymetry, soil stratigraphy, hazardous and risky areas on the seafloor
Geotechnical surveys	Within the proposed wind farm site and along cable routes.	To identify soil/rock strata boundaries & engineering properties or specific sea floor features; to monitor the soil behaviour under the constant dynamic loading on the foundation by the wind, waves and current, and to improve the geological model prior to the design and installation of foundations.	Boreholes with soil/rock sampling, and cone penetration testing (CPT).	Sea bed soil stratigraphy in upper 5m for cables, and 50-70m on physical characteristics.
Hydrographic surveys	Along transects across zones within the proposed wind farm site and cable routes.	To examine the OWF impact on local sedimentation and coastal processes such as erosion.	Post-construction monitoring	Sedimentation environment related to scour characteristics of the site
Weather forecasting and metocean data	Within OWFs and between OWF and coast	Forecasts to support short-term planning of offshore activities; Observations to support offshore activity, to verify forecast tools and to resolve disputes regarding weather downtime	Weather models, lidar, wave buoys, current meter etc.	Forecasts: wind profiles, waves and visibility, lightning risk, fog, etc. Observations: winds, waves, currents

Table S3. An overview on other required monitoring activities

Monitoring activity	**Sampling locations**	**Purpose**	**Sampling method**	**What to measure**
Data for corrosion protection	Within OWFs	To assess corrosion rate and potential risks	Metocean sensors, modelling	Humidity, icing, salinity, waves etc.
Data for scour protection	Turbine foundations	To estimate scour rate of the sea bed caused by the speed-up of water moving around the foundation	Not specified	Sediment particle size distribution and the strength, waves, currents, scour depths, depth of non-cohesive sediments.
Data for offshore cable installation and protection	Along cable lines	To support subsea cable protection and installation by defining an optimal route, assessing sediment layer thickness above the cable, and identifying vulnerable locations.	Models; vibrocores and CPTs up to 5m under sea bed; sediment samples; magnetometry; ROVs.	A survey to define the route and identify any UXO, followed by a pre-lay grapnel run (or alternative method) to clear debris from the cable route.
Operation and condition monitoring	With OWF	To support OWF operation and real-time health check and repair	SCADA, ROVs, Service Operation Vessel (SOV)	Windmill operational status variable, winds
Environmental monitoring in operational period	Within the farm	To understand the effect of the wind farm on the local environment and wildlife	Not specified	Not specified
Monitoring for turbine inspection	Within OWF	To inspect turbine's health condition	Unmanned aerial vehicles (UAVs, mostly multi-rotor copter drones equipped with a digital, thermographic camera)	Visual images of tower, nacelle, rotor blades and bolt jointing; Thermographic image on blade
Environmental surveys for decommissioning	Within OWF	To support post-decommissioning management of the site in line with the Energy Act 2004	Before and after decommissioning. No details specified on the method	Not specified

References:

1. The Crown Estate and the Offshore Renewable Energy Catapult (2019). Guide to an offshore wind farm, published by *BVG Associates Limited - © BVG Associates*, pp128.