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ENERGY ISLAND BORNHOLM
SCOPING REPORT – UNDERWATER NOISE AND VIBRATIONS

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CONTENTS

1. SUMMARY

This scoping report defines the work to be carried out in relation to the modelling and assessment of the underwater noise as input to the Strategic Environmental Assessment for Energy Island Bornholm. The report defines the area and activities to be assessed, the overall methodology for performing the underwater sound propagation modelling and indicating the marine impact threshold limits which will be used in the Environmental Assessment.

2. INTRODUCTION

The energy islands mark the beginning of a new era for the generation of energy from offshore wind, aimed at creating a green energy supply for Danish and foreign electricity grids. Operating as green power plants at sea, the islands are expected to play a major role in the phasing-out of fossil fuel energy sources in Denmark and Europe.

After political agreement on the energy islands have been reached, the Danish Energy Agency plays a key role in leading the project that will transform the two energy islands from a vision to reality. The islands are pioneer projects that will necessitate the deployment of existing knowledge into an entirely new context.

In the Baltic Sea, the electrotechnical equipment will be placed on the island of Bornholm, where electricity from offshore wind farms will be routed to electricity grids on Zealand and neighbouring countries. The offshore wind farms will be established approximately 15 km south-southwest of the coast and will be visible to the naked eye, but not dominate the horizon. Th The turbines off the coast of Bornholm will have an installed production capacity of up to 3,8 GW including overplanting. The planned areas for the two offshore wind farms are shown in Figure 2-1.

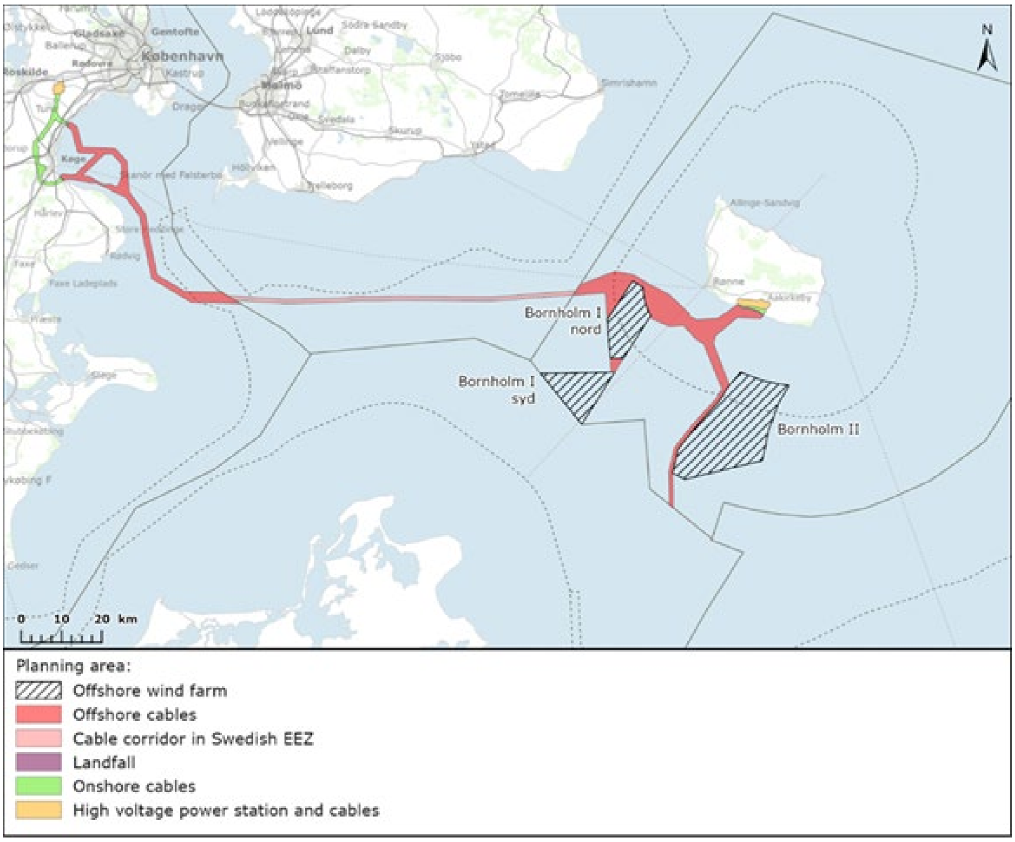

Figure 2-1 Energy Island Bornholm.

The construction and operation of an offshore wind farm involves activities that produce underwater noise where pile driving have the potential to disturb or harm marine mammals and fish in the area.

The purpose of this study is to provide the expected potential underwater noise levels and exposure levels needed for assessments of potential impact on the harbour porpoise population, seals and fish and provide relevant documentation as part of the Environmental permitting process. The study includes the significant activities for the following phases:

- Construction
    - Monopile pile driving with and without noise mitigation

The modelling will be performed in accordance with environmental assessments of similar OWFs and DEA has guidelines on underwater noise assessment for monopile-driving: Energistyrelsen: *Guideline for underwater noise – installation of impact-driven piles. April 2016*. The guideline forms the basis for calculation and assessment of underwater noise. Ramboll is aware that the DEA currently is updating the existing guidelines. The updated guidelines are expected to be available in Q2 of 2022 and will include new impact threshold limits.

For each design option of the project, significant "worst-case" noise sources will be identified, and based on this, representative modelling positions will be chosen. The modelling is based on the design for the actual project to the extend concrete technical data is available, while a "worst-case" assumption will be applied for currently unspecified inputs. The modelling includes the determination of impact ranges (distances) from the various activities where potential impact can occur.

3. AREA OF INVESTIGATION

Rambøll will together with Energinet choose 3-4 representative positions within each of the two wind farm areas (see Figure 2-1). At each position underwater noise from monopile pile driving with and without noise mitigation will be modelled.

4. METHODOLOGY

4.1 Noise modelling positions

Rambøll will choose modelling positions and phases modelled for underwater noise as representative 3-4 positions for each of the 2 whole sites. Energinet will prepare a "Technical Project Description" for use in the modelling and assessment work.

4.2 Underwater sound

Underwater sound, like sound in the air, is disturbances from a source in a medium – here water – travelling in a 3-dimensional manner as the disturbances propagates with the speed of sound.

Sound travels at different speeds in different medias. The speed of sound is determined by the density and compressibility of the medium. Density is the amount of material in a given volume, and compressibility is a measure of how much a substance could be compressed for a given pressure. The denser and the more compressible the media is, the slower the sound waves will travel. Water is much denser than air, but since it is nearly incompressible the speed of sound is about four times faster in water than in air. The speed of sound can also be affected by temperature. Sound waves tend to travel faster at higher temperatures.

Underwater sound can be measured as a change in pressure and is described as sound pressure and can be measured with a pressure sensitive device (hydrophone).

Because of the large range pressure amplitudes of sound, it is convenient to use a decibel (dB) logarithmic scale to quantify pressure levels. The underwater sound pressure level in decibels (dB) is defined in the following equation:

Sound Pressure Level (SPL) = $20\log_{10}(P/P_0)$

P is the pressure and P_0 is the reference pressure. The reference pressure is 1 micropascal (μPa) for underwater sound which is different from sound pressure levels in the air. For this reason, sound pressure levels in the water and air cannot be directly compared.

Underwater sound levels vary with the sound source's time signature and acoustic environmental conditions. Therefore, noise levels are defined in terms of exposure, average and/or maximum levels. The following acoustic parameters are commonly used to assess the noise impact from underwater noise sources for the identified local marine life.

4.3 Applicable acoustic parameters

The following key terms are used in this document:

Sound Pressure Level (SPL) – this quantifies the magnitude of a sound at a given point, i.e. how loud it is and is measured in decibels (dB). As a relative unit, dB is quoted relative to 1 micropascal in underwater studies (so, dB re 1 μPa).

$$SPL = 10\ \log_{10}\left[\frac{\hat{p}^2}{p_0^2}\right] = 20\ \log_{10}\left[\frac{\hat{p}}{p_0}\right]$$

Sound Exposure Level (SEL) – this is a decibel measure for describing how much sound energy a receptor (e.g., a marine mammal) has received from an event and is normalized to an interval of one second (quoted in dB re. 1 $\mu Pa^2 s$). It can be thought of as a logarithmic measure of Sound Exposure and hence a 3 dB increase in SEL equates to a doubling of sound energy; dB re. 1 $\mu Pa^2 s$.

$$SEL = 10\ \log_{10}\left[\frac{E}{E_0}\right]$$

Cumulative Sound Exposure (SEL (cum)) – this is the time integral of the squared pressures over the duration of a sound or series of sounds. It enables sounds of differing duration and level to be characterized in terms of total sound energy normalized to an interval of one second (quoted in dB re. $Pa^2 s$). SELcum is the cumulated SEL over a noise-causing activity (e.g. pile driving).

Peak pressure level (PEAK) – the zero-to-peak sound pressure at a given point in time.

$$L_{peak} = 20\ \log_{10}\left[\frac{p_{peak}}{p_0}\right]$$

Root mean square (RMS) – the sound pressure averaged over a given time; The RMS SPL is commonly used to evaluate the effects of continuous noise sources. The RMS sound pressure level or SPL is the mean square pressure level.

Pulsed/impulsive sound – a discontinuous sound source comprising one or more instantaneous sounds as during munitions clearance.

Continuous sound – sound source, like a vessel engine, or humming as in drilling operation.

4.4 Underwater sound source levels

Based on existing underwater sound measurements, we will estimate the sound source levels and frequency spectrum for the identified significant sound sources for potential underwater noise impacts. Where applicable, in order to obtain an equivalent source level at 1 m from the source, for the purpose of acoustic propagation modelling, we will back-propagate the pressure field according to cylindrical spreading loss, or 15·log(r). The purpose of the back-propagation step is to determine the effective source level at 1 m that will be used in the acoustic propagation model.

4.5 Underwater sound propagation model

The underwater sound propagation model calculates estimates of the sound field generated from underwater sound sources. The results of the modelling are used to determine the potential impact distances (noise maps/contour plots) from the identified significant underwater noise sources for the various identified marine life in the area. Based on source location and underwater source sound level, the acoustic field at any range from the source is estimated using dBSEA's acoustic propagation model (Parabolic equation method (≤500 Hz), Jensen 2011 and ray tracing (>500 Hz)). The sound propagation modelling uses acoustic parameters appropriate for the specific geographic region of interest, including the expected water column sound speed profile, the bathymetry, and the bottom geo-acoustic properties, to produce site-specific estimates of the radiated noise field as a function of range and depth. The acoustic model is used to predict the directional transmission loss from source locations corresponding to receiver locations. The received level at any 3-dimensional location away from the source is calculated by combining the source level and transmission loss, both of which are direction dependent. Underwater acoustic transmission loss and received underwater sound levels are a function of depth, range, bearing, and environmental properties. The output values can be used to compute or estimate specific noise metrics relevant to safety criteria filtering for frequency-dependent marine mammal hearing capabilities.

Underwater sound source levels are used as input for the underwater sound propagation program, which computes the sound field as a function of range, depth, and bearing relative to the location of the source.

The model assumes that outgoing energy dominates over scattered energy and computes the solution for the outgoing wave equation. An approximation is used to provide two-dimensional transmission loss values in range and depth, i.e., computation of the transmission loss as a function of range and depth within a given radial plane is carried out independently of neighbouring radials (reflecting the assumption that sound propagation is predominantly away from the source).

The received underwater sound levels at any location within the region of interest are computed from the 1/3-octave band source levels by subtracting the numerically modelled transmission loss at each 1/3-octave band center frequency and summing across all frequencies to obtain a broadband value. For this study, transmission loss and received levels were modelled for 1/3-octave frequency bands between 10 and 80000 Hz. Because the source of underwater noise considered in this study are predominantly low-frequency sources, this frequency range is sufficient to capture essentially all of the energy outputs. The received levels will be converted to all the applicable underwater acoustic parameters.

Bathymetry data will be provided from EMODNET (The European Marine Observation and Data Network).

Water column data (Salinity, Temperature, Speed of underwater sound/depth) will be provided from ICES (International Council for the Exploration of the Sea) HELCOM specific measurement stations positioned close to the selected modelling positions.

Seabed Conditions (Sand, Clay /depth) are provided from Ørsted geological survey data for areas close to the modelling positions.

Predictions have been performed for both winter (worst month) and summer water column conditions which have different underwater sound propagation characteristics and will show the maximum underwater noise level of the whole sea depth.

The sound propagation model will run with the source levels, activity time and environmental parameterization and generate noise maps. The levels depicted in the noise maps will be the maximum predicted level for that location at any depth down to the bottom and will include the following acoustic parameters for each of the identified sound sources:

- SEL, Sound Exposure Level (linear, VHF and PCW weighted), dB re. 1μPa^{2}s
- SELcum, Cumulative Sound Exposure Level (Linear, VHF and PCW weighted), dB re. 1μPa^{2}s
- SPL, RMS levels (linear), dB re. 1μPa
- SPL, Peak (linear), dB re. 1μPa

The results of the acoustic modelling (noise maps and impact distances) will be reported in terms of the underwater sound levels of each specific acoustic metric for distances up to 50 km. As well, a vertical sound propagation profile plot for the dominant sound source frequency bands will be generated to show the variation in underwater sound propagation in regard to sea depth.

4.5.1 Baseline for the impact assessment of underwater noise

The pressure levels of the sound source and the associated impact zones can be viewed as indicative precautionary ranges. It is important to note that it is highly unlikely that any marine mammal would stay at a stationary location or within a fixed radius of any other noise source. The behaviour of receivers (animals) will be included in a model of exposure. A worst-case assumption of a stationary animal can be made, but this is likely to overestimate the extent of especially the impact threshold zones considerably and therefore included is a simple model for animal escape, including a threshold for reaction followed by movement radially away from the sound source. Marine mammal movement will be modelled as a movement with a speed of 1.5 m/s.

Fish are assumed to flee differently (Anderson 2017) from the noise source. Fish fleeing will be modelled in calculating the sound exposure level. There is not enough data or understanding of the behaviour of fish during pile driving to include in our modelling of the cumulative sound exposure.

Ramboll is aware that the DEA currently is updating the existing guidelines. The updated guidelines are expected to be available in Q2 2022 and will include new impact threshold limits which are based on Southall 2019 threshold limits

4.5.2 Marine mammals

Generally, the effect of noise on marine mammals can be divided into four broad categories that largely depend on the individual’s proximity to the sound source:

- Detection
- Masking
- Behavioural changes
- Physical damages

The limits of each zone of impact are not sharp, and there is a large overlap between the zones. The four categories are described below, based on Southall et al 2007.

Detection ranges depend on background noise levels as well as hearing thresholds for the animals in question.

<u>Masking</u> occurs when <u>noise</u> interferes with an animal's ability to <u>perceive</u> (detect, interpret, and/or discriminate) a sound. There are still many uncertainties regarding how masking affects marine mammals.

The occurrence and significance of a **behavioural change** varies by individual, species, and circumstances. Some sounds may not cause any response, while others may result in minor to significant changes in a variety of behaviours, such as diving, surfacing, feeding, vocalizing and/or mating.

Physical damage to marine mammals relates to damage to the hearing apparatus. Physical damages to the hearing apparatus may lead to permanent changes in the animals' detection threshold (permanent threshold shift, PTS). This can be caused by the destruction of sensory cells in the inner ear, or by metabolic exhaustion of sensory cells, support cells or even auditory nerve cells. Hearing loss is usually only temporary (temporary threshold shift, TTS) and the animal will regain its original detection abilities after a recovery period. For PTS and TTS, the sound intensity is an important factor for the degree of hearing loss, as is the frequency, the exposure duration, and the length of the recovery time.

The proposed criteria for PTS, TTS and behavioural response in this report are based on results presented in scientific literature and/or commonly and currently used in environmental impact assessments of underwater sound. The behaviour of receivers (animals) is essential to include in a model of exposure.

4.5.3 Marine mammal auditory weighting function

The ability to hear sounds varies across a species' hearing range. Most mammal audiograms have a typical "U-shape," with frequencies at the bottom of the "U" being those to which the animal is more sensitive, in terms of hearing. Auditory weighting functions best reflect an animal's ability to hear a sound (and do not necessarily reflect how an animal will perceive and behaviourally react to that sound). To reflect higher hearing sensitivity at particular frequencies, sounds are often weighted. Auditory weighting functions have been proposed for marine mammals, specifically associated with PTS/TTS acoustic thresholds expressed in the SELcum metric, which take into account what is known about marine mammal hearing (Southall, 2019). Very High Frequency (VHF) weighted impact threshold limits are applicable to Harbour Porpoises. Phocid Carnivores in Water (PCW) weighted threshold limits are applicable to Seals.

4.5.4 Noise source characteristics

When analysing the auditory effects of noise exposure, it is often helpful to broadly categorize noise as either impulse noise — noise with high peak sound pressure, short duration, fast rise-time, and broad frequency content — or non-impulsive (i.e. steady state) noise. When considering auditory effects, sonars, other coherent active sources, and vibratory pile driving are considered to be non-impulsive sources, while explosives, impact pile driving, and air guns are treated as impulsive sources. Note that the terms non-impulsive or steady-state do not necessarily imply long duration signals, only that the acoustic signal has sufficient duration to overcome starting transients and reach a steady-state condition. For harmonic signals, sounds with duration greater than approximately 5 to 10 cycles are generally considered to be steady state.

4.5.5 Harbour porpoise criteria (current assumed).

Table 5-1 summarizes criteria for assessing impacts for marine mammal (Harbour Porpoise). The criteria are associated with different impacts and limits. These threshold values for impact have been determined by an assessment of available values from the most recent scientific literature and accepted limits. (Tougaard, 2016 and Southall 2019, German limits 2011). The German limits are maximum levels for SEL and Peak levels at 750 meters from the source and are primarily used for pile driving.

Table 4-1 Harbour porpoise noise exposure criteria for hearing loss*.

Species	Functional hearing group	Noise effect	Threshold (Impulsive noise)*	Threshold (Non-impulsive noise)*	Reference
Harbour porpoise	Very High-frequency cetaceans VHF	PTS	155 dB re 1μPa²s SELcum (weighted)	173 dB re 1μPa²s SELcum (weighted)	*Southall et al. 2019*
		TTS	140 dB re 1μPa²s SEL cum(weighted)	153 dB re 1μPa²s SELcum (weighted)	*Southall et al. 2019*

*To be updated with the forth coming DEA guidelines.

Table 4-2 Harbour porpoise noise exposure criteria for behavioural displacement (current assumed)*.

Species	Noise type	Threshold	Reference
Harbour porpoise	Impact piledriving	100 dB re 1μPa rms (VHF weighted)	*Tougaard 2016*

*To be updated with the forth coming DEA guidelines.

4.5.6 Seals criteria (current assumed)

Table 4-3 summarizes criteria for assessing impacts for marine mammal (Seals). The criteria are associated with different impacts and limits. These threshold values for impact have been determined by an assessment of available values from the most recent scientific literature and accepted limits. (Russel 2016, Southall 2019) Detection distances were not determined in this study for seals as they are less sensitive to underwater noise than Harbour porpoises.

Table 4-3 Seal noise exposure criteria for hearing loss*.

Species	Impact type (Reference)	Fleeing speed [m/s]	Impulsive noise criteria [dB] SEL	Continuous noise criteria [dB] SEL
Seal	PTS (Southall 2019)	1.5	185 PCW (cum)	201 PCW (cum)
Seal	TTS (Southall 2019)	1.5	170 PCW (cum)	181 PCW (cum)
Seal	Behaviour (Russel 2016)	-	151 (single strike)	n/a

*To be updated with the forth coming DEA guidelines.

4.5.7 Offshore pile driving noise limits (Germany)

Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has created guidelines for how to protect the marine mammals from harmful effects during the construction of offshore wind farms in the German exclusive economic zone in the North Sea (BMUB, 2014). The underwater noise generated by pile driving operations at offshore wind farms can have significant adverse effects on marine mammals, both on the individual and the population level. The guidelines recommend utilizing the best available technology to minimize noise exposure and other adverse effects on the marine environment. The German Federal Maritime and Hydrographic Agency (BSH) has established a dual threshold for permissible noise levels, which must not be exceeded at 750 meters away from the source, of SEL 160 dB re 1 μPa^2s or SPL (peak) 190 dB re 1 μPa. In areas where noise levels are above the threshold value, intrusive methods such as acoustic deterrent (soft-start or seal scarers) should be used to minimize the risk of injury to the animals. These limits have often been adopted for Swedish offshore projects and are included here to show how the underwater noise from the identified activities compare to these limits.

Currently, we will also show VHF, PCW weighted levels at 750 meters as specified on other Swedish projects. (Århus University, Swedish authorities). However, will consider excluding the German unweighted limits but we will keep them at the moment and save it if relevant. The problem with the German limits, as they underestimate the effect of the bubble curtain. The numbers are not well founded.

Table 4-4 German underwater noise limits (Maximum allowable at 750 meters from the noise source).

Species	Max. SEL @ 750 meters** dB re. $1\mu Pa^2s$	Max. Peak @750 meters ** dB re. 1μPa
Marine mammals	160 dB	190 dB

4.5.8 Fish

Sound, at higher intensities, may have a diverse range of effects on fish. These may include death, hearing impairment, damage to anatomical structures, and changes in physiology, neural function, behaviour, and development.

4.5.9 Fish criteria

Table 4-5 summarizes criteria for assessing impacts for fish. The criteria are associated with different impacts and limits. These threshold values for impact have been determined by an assessment of available values from the most recent scientific literature and accepted limits. (Popper 2014, Andersson et al 2017).

Definition of Effects

- *Mortality and mortal injury:* immediate or delayed death.
- *Recoverable injury*: injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality.
- *TTS:* short- or long-term changes in hearing sensitivity that may or may not reduce fitness.

Exposure distances for herring and cod including escape rates. For herring we will use 1.04 m/s and for cod we have used 0.38 m/s (juvenile) and 0.9 m/s (adult).

Table 4-5 Threshold criteria level and impact distances for fish.

Species	Impact type (Reference)	Fleeing speed [m/s]*	Impulsive noise criteria [dB] Peak	Impulsiv noise criteria [dB] SEL	Continuous noise criteria [dB]SEL
Fish	Mortal injury (Popper 2104)	0	207	207 (cum)	-
Fish	Recoverable injury (Popper 2014)	0	207	203 (cum)	222 (cum) 48 hours, 170 rms
Fish	TTS (Popper 2014)	0	-	186 (cum)	204 (cum) 12 hours, 158 rms
Larvae	Mortal injury (Popper 2014)	0	207	210 (cum)	

4.6 Underwater sound source model inputs

The noise sources (pile driving with, without mitigation and operation) of the project will be identified and give their respective sound source levels, characteristics and frequency spectrum. These parameters will be determined based on available measurement data and adjusted to meet the OWF proposed design concepts and will be used as input to the underwater sound propagation model.

4.6.1 Pile driving source levels

We will use the 1/3-octave spectrum from Bellmann et al. (2020) as that represents the most up-to-date and comprehensive collection of spectra. dBSEA source levels (without mitigation) to be adjusted to meet levels for a design worst case diameter monopile at 750 meters as shown here:

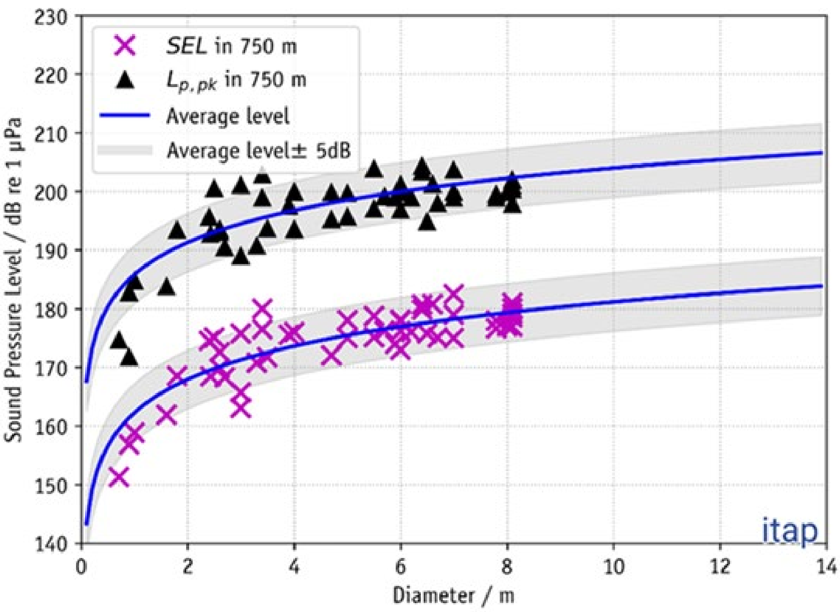

Figure 4-1 Measured data for pile driving (Bellmann et al. 2020).

With a spectrum below without mitigation.

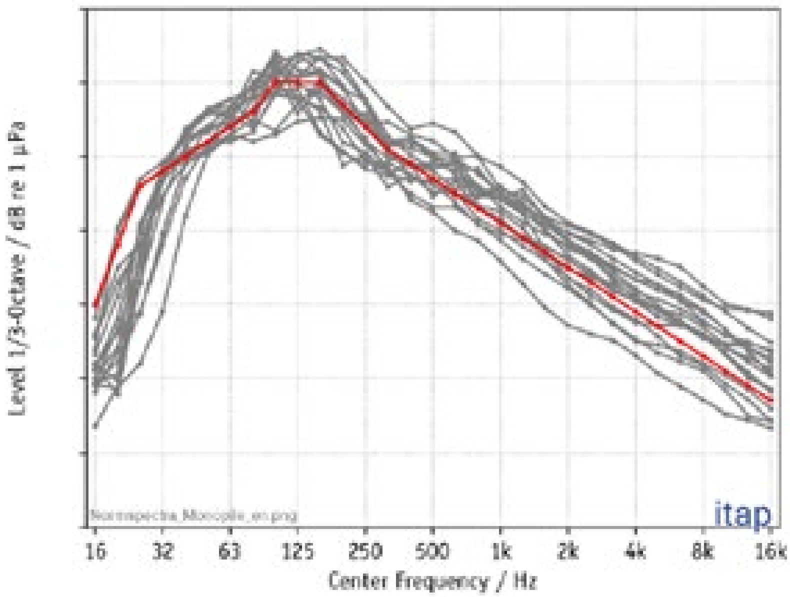

Figure 4-2 Spectrum data (Bellmann et al. 2020).

4.6.2 Pile driving schedule

Ørsted will provide a representative piling profile schedule with estimated number of strikes, soft start program with hammer energy. The pile driving schedule that should be used for the SELcum calculations.

4.7 Noise mitigation

Noise mitigation systems are planned to be used for the impact piling if mono piles will be used to meet the "german" limits. A description of the noise mitigation systems will be provided. Based on available published data the noise mitigation systems *Big Bubble Curtain* (BBC) and *Hydro Sound Damper* are well approved technics under real offshore-applications.

The mitigation (HSD+DBBC) transmission loss data for pile driving is shown in Figure 4-3

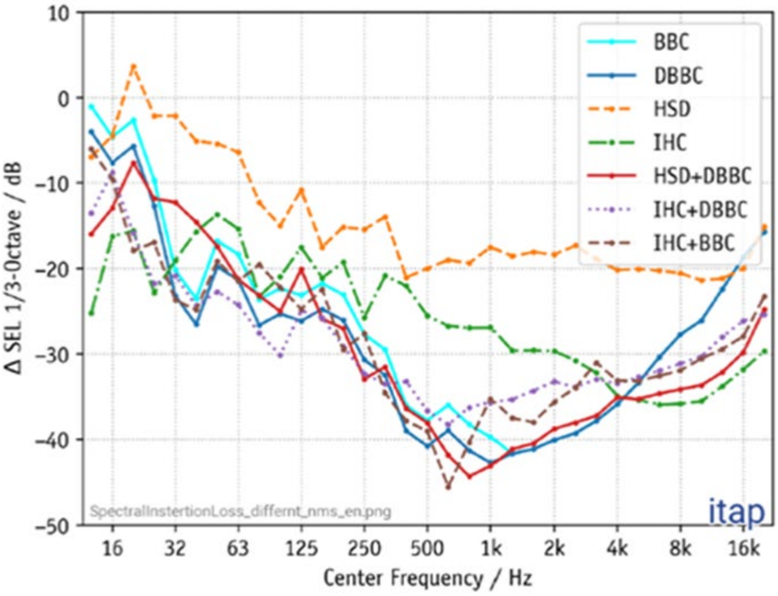

Figure 4-3 Noise mitigation reduction spectrum (Bellmann et al. 2020).

4.8 Geoacoustic modelling inputs

4.8.1 Bathymetry

The relief of the sea floor is an important parameter affecting the propagation of underwater sound, and detailed bathymetric data are therefore essential to accurate modelling. A base-level-resolution bathymetric dataset for the entire study area will be obtained from public EMODNET (The European Marine Observation and Data Network).

4.8.2 Geoacoustic properties

Seabed layer information will be gathered from the available Geological survey data for areas close to the modelling positions and used in the modelling provided by the project.

4.8.3 Sound speed profiles/salinity

Water column data (Salinity, temperature/Depth) will be provided from ICES (International Council for the Exploration of the Sea) HELCOM specific measurement stations positioned close to the selected modelling positions. This data is used to calculate the sound speed profile for the modelling positions and used as input in the underwater sound propagation model. The salinity was set at 9.2 to 9.6 PSU (summer - winter) to calculate the underwater sound absorption coefficient (Ainslie and McColm, 1998).

Predictions will be performed for both winter (worst month) and summer water column conditions which have different underwater sound propagation characteristics.

4.9 Underwater noise modelling results

The sound propagation model will be run with the source levels, source spectrum and environmental parameterization described in previous sections. The distances predicted to the various threshold limits will be the maximum at any depth down to the bottom. The results of the acoustic modelling will be in terms of the maximum average radial distances from the investigation activities to the applicable assessment underwater noise threshold levels specified.

Also, with noise maps. The results of this study will be to provide the expected potential underwater noise levels and exposure levels needed for assessments of potential impact on the harbour porpoise population, seals and fish and provide relevant documentation as part of the Environmental permitting process.

5. DELIVERABLES

The deliverables under this work package (WP K) consist of:

- A scoping report describing on what data and with which methods the technical report will be based.
- A technical report on the underwater noise propagation from pile-driving during construction and an assessment on potential impacts on marine mammals and fish.

6. MILESTONES

Table 6-1 shows the major milestone and deadlines for deliveries related to underwater noise modelling (WP K).

Table 6-1 Milestones and deadlines for all work packages.

Work package	Milestone No.	Milestone	Deadline
WP K	M56	Scope report 1st draft	Q4 2021
WP K	M57	Scope report Final version	Q4 2021
WP K	M58	Technical report 1st draft	TBD
WP K	M59	Technical report Final draft, including appendices and data (input to SEA)	TBD
WP K	M60	Technical report Final version	TBD

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