# Appendix C-4 Addendum

## Comprehensive Review of Relevant Mitigation (Noise Abatement)

ORIEL WINDFARM
OFFSHORE RENEWABLE ENERGY

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# ORIEL WIND FARM PROJECT

## Natura Impact Statement Addendum

## Appendix C-4 Addendum: Comprehensive Review of Relevant Mitigation (Noise Abatement)

MDR1520C
NIS– Appendix C-4
Addendum
A1 C01
December 2025

rpsgroup.com

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## Tables

# Glossary

| Term | Meaning |
|---|---|
| Acoustic Deterrent Device | Non-lethal management measures that work by introducing noise. |
| Anthropogenic | An activity resulting from or relating to the influence of humans |
| Echolocation | A process for locating distant or hard-to-see objects using the reflection of sound waves. |
| Impulsive sound | Sound characterised by sudden, short-duration and rapid increase in sound pressure (the duration of a single impulse sound is usually less than 1 second). |
| Noise Abatement Systems | System which generates a ‘barrier’ to reduce sound propagated through the water column |
| Noise Mitigation Systems | System which reduces sound ‘at source’, achieved by dampening, blocking, absorbing or altering how the sound propagates. |
| Permanent Threshold Shift | A permanent increase in the threshold of hearing (minimum intensity needed to hear a sound) at a specific frequency above a previously established reference level. |
| Resonator | Underwater inverted air-filled cavities with combinations of rigid and elastic wall members, fastened to framework to form a stationary array surrounding a noise source. |
| Sound Exposure Level | Measure of energy that takes into account both the received level and duration of exposure and can be calculated for a single pulse. |
| Sound Pressure Level | Unweighted metric in which the peak SPL represents the highest pressure level of the sound source. |
| Temporary Threshold Shift | A temporary increase in the threshold of hearing (minimum intensity needed to hear a sound) at a specific frequency that returns to its pre-exposure level over time. |
| Wave reflection | Deflection or bouncing back of sound wave by an object, rather than propagating forward. |

# Acronyms

| Term | Meaning |
|---|---|
| ACP | An Coimisiún Pleanála |
| ADD | Acoustic Deterrent Device |
| AGESCIC | Achieve Good Environmental Status for Coastal Infrastructures Construction |
| BBC | Big Bubble Curtain |
| DBBC | Double Big Bubble Curtain |
| EEZ | Exclusive Economic Zone |
| EIAR | Environmental Impact Assessment Report |
| GABC | Grout Annulus Bubble Curtain |
| GES | Good Environmental Status |
| GHG | Greenhouse Gas |
| HSD | Hydro Sound Damper |
| JNCC | Joint Nature Conservation Committee |
| LBC | Little Bubble Curtain |
| MNRU | MENCK Noise Reduction Unit |
| MODIGA | Monopile Offshore Drilling Installation & Grouting Aid |

| Term | Meaning |
|---|---|
| MSFD | Marine Strategy Framework Directive |
| NAS | Noise Abatement Systems |
| NMS | Noise Mitigation Systems |
| NPWS | National Parks and Wildlife Service |
| OWF | Offshore Wind Farm |
| PE | Polyethylene |
| PTS | Permanent Threshold Shift |
| PULSE | Piling Under Limited Stress Equivalent method |
| RFI | Request for Further Information |
| SAS | Sound Attenuation System |
| SBC | Small Bubble Curtain |
| SEL | Sound Exposure level |
| SI | Statutory Instrument |
| SPL | Sound Pressure level |
| TRAC | Transportation Centre |
| TTS | Temporary Threshold Shift |
| UXO | Unexploded Ordnance |
| WTG | Wind turbine generation |

# Units

| Unit | Description |
|---|---|
| dB | Decibel |
| Hz | Hertz |
| kHz | Kilohertz |
| Km | Kilometres |
| m | Metres |

# 1 INTRODUCTION

This Technical Report has been prepared in response to a Request for Further Information (RFI) from An Coimisiún Pleanála (formerly An Bord Pleanála) regarding the planning application (case reference ABP-319799-24) for the Oriel Wind Farm Project (hereafter referred to as “the Project”). Specifically this Technical Report provides a response to RFI 9.Ai and 9.Aii regarding underwater noise mitigation and abatement for marine mammals and megafauna as listed in the ‘Schedule - Further Information Request’ provided by An Coimisiún Pleanála (ACP) and outlined in Table 1-1.

**Table 1-1: Further information requested regarding underwater noise mitigation and abatement for marine mammals and megafauna and details on Applicant’s response.**

| Reference | Request for Further Information: | Reference where information is presented in Technical Report |
|---|---|---|
| **9A** | The details that have been submitted in relation to underwater noise arising from the proposed development acknowledges the potential for impacts to arise on marine fauna from both Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) over significant areas. The Wildlife Act 1976, as amended, lists marine mammals, including all dolphin, porpoise, seal and whale species as protected (with subsequent regulations also applying protections to all species of marine turtles and similar protections to basking sharks), stating that it is an offence to hunt, injure, or wilfully interfere with/destroy the resting or breeding place of such species. The January 2014 National Parks and Wildlife Service (NPWS) ‘Guidance to Manage the Risk to Marine Mammals from Man-Made Sound Sources’ published by the Department of Arts, Heritage and the Gaeltacht (NPWS (2014)), notes that sound sources with the potential to induce TTS in a receiving marine mammal has the potential to cause both disturbance and injury. This guidance has a statutory basis under Regulation 71 of SI No. 477 of 2011, and refers to the “offence to injure” under the Wildlife Act, 1976, noting that TTS “may constitute such an injury”.<br>Having regard to the information submitted in the EIAR, the NPWS underwater noise guidelines (NPWS, 2014), the strict protections afforded to marine mammals under the Wildlife Act 1976, as amended, in addition to submissions from prescribed bodies and observers, the Board requires a comprehensive suite of noise abatement measures to be submitted and assessed in addition to the existing mitigation measures referenced in the planning documentation. The applicant is requested to submit: | n/a |
| **9.Ai** | A comprehensive review of relevant mitigation, in addition to what is currently contained in the submitted documentation, specifically appropriate noise abatement measures, which could be applied to the proposed development to reduce/restrict the propagation of noise through the marine environment and provide realistic values for the reduction in sound level possible from these technologies. The review must consider the range of suitable abatement measures available, including consideration of, at a minimum, bubble curtains, casings, resonators, and alternative hammer/piling technologies to reduce noise emissions and set out in detail the suitability of such measures for the construction of the proposed development at this location, including restrictions in relation to their suitability, where relevant. | See sections 1.2 and 1.3 |
| **9.Aii** | The applicant must also consider and draw on the best available technology and thresholds, including as applied in other EU jurisdictions (e.g. Germany; Belgium; Netherlands; Denmark), to identify and provide for suitable noise abatement to reduce the level and extent of potential noise impacts arising from the proposed development. Examples include the German 160 dB re 1 μPa²s SEL*ss* and 190 dB re 1 μPa SPL*peak* thresholds that must not be exceeded at a distance of 750m from a piling site; or the frequency weighted SEL*cum* PTS thresholds (e.g. harbour porpoise 155 dB re 1μPa2s) that must not be exceeded for a fleeing animal with a starting distance of 200m in Denmark. | See section 1.1 |

The assessment of injury and/or disturbance to marine megafauna from underwater noise during pile driving at the Project (see NIS appendix F: Marine Mammals and Megafauna Supporting Information) concluded no significant impact (slight adverse for PTS, slight adverse/imperceptible for temporary threshold shift and slight adverse for disturbance) for marine mammal and megafauna receptors

The Project however is committed to the consideration of noise abatement measures, for the purposes of reducing sound levels from construction piling, if considered necessary. In response to ACP, RFI 9Ai & ii this Technical Report summarises available and 'in-development' engineering mitigation techniques and sound reduction measures, providing a comprehensive review of relevant mitigation that could be applied at the Project.

Any selected technologies to be applied to the Project will need to be tailored to the specific environmental conditions and final project design and therefore some technologies may not be viable options; this has been discussed further in section 1.5. The Applicant has therefore compiled research on the available and in-development sound reduction technologies to aid in determining viable options, if required.

This Technical Report presents and summarises publicly available information on sound reduction potential with respect to sound exposure levels (SEL) and/or sound pressure levels (SPL), for currently available technologies. SPL is an unweighted metric in which the peak SPL ($SPL_{pk}$) represents the highest pressure level of the sound source, irrespective of the frequency content of the signal. SEL is a measure of energy that takes into account both the received level and duration of exposure and can be calculated for a single pulse (often referred to as single-strike ($SEL_{ss}$)) or multiple pulses for the cumulative sound energy ($SEL_{cum}$). $SEL_{ss}$ is most often presented in studies of sound reduction measures and is usually an unweighted value, but some studies have also investigated frequency-dependant reductions in dB, which can be compared to relevant published marine mammal hearing weightings (NMFS, 2024; Southall *et al.*, 2019).

Acoustic modelling for both single Noise abatement systems (NAS) and double NAS configurations has been completed in response to RFI 9.A.iii and is included in appendix C-2 Addendum: NAS Modelling Report, with the subsequent impact of NAS on marine mammals, megafauna and fish included in appendix C-3 Addendum: NAS Comparison Technical Note – Marine Mammals, Megafauna and Fish.

## 1.1 Overview

It is considered that there are two main mitigation approaches to reducing sound levels:

- Noise mitigation systems (NMS) (section 1.2), which reduce sound 'at source', achieved by dampening, blocking, absorbing or altering how the sound propagates.
- NAS (section 1.3) which generate a 'barrier' to reduce sound propagated through the water column.

These two main mitigation approaches are not mutually exclusive, and it is possible that both NMS and NAS can be combined to achieve a higher degree of sound reduction (Elmer and Savery, 2014; Oestman *et al.*, 2009; Verfuss *et al.*, 2019; Wagenknecht, 2021), as demonstrated recently during construction of windfarms in Germany (Buljan, 2024).

The Applicant considers noise mitigation is likely to become increasingly important in Ireland, particularly with the release of recent guidance in the UK. For example, Defra (2025b) released their Marine Noise Policy Paper on methods to reduce noise in the marine environment which refers to multiple sources of marine noise that may be harmful to marine life. The Defra policy statement also includes cross-reference to recently updated position papers (as of January 2025) with respect to piling methods (JNCC, 2025) and UXO clearance (Defra, 2025a).

To date, in Ireland there has not been a requirement to implement any regulatory measures mandating the use of NAS and/or NMS as has been the case for other jurisdictions. The EU's Marine Strategy Framework Directive (MSFD) includes provision for underwater noise pollution (Descriptor 11) in its description of Good Environmental Status (GES) (European Commission, 2008), which seeks to ensure that the 'introduction of energy, including underwater noise, is at levels that does not adversely affect the marine environment' (European Commission, 2017). As such various EU countries have established a decibel limit during construction to reduce the risk of serious environmental impacts from anthropogenic sound sources such as pile driving (Table 1-2). Germany, Belgium, Netherlands and Denmark, for example, have stringent sound reduction legislation (Table 1-2) and NAS and NMS are frequently employed to reduce piling noise during the construction of offshore wind farms. Currently, the UK does not have any established national decibel limits.

**Table 1-2: List of national decibel limits for effects on marine mammals.**

| Country | Decibel limit | Reference |
|---|---|---|
| Belgium | Impulsive sound (zero-to-peak sound pressure level ($L_{0\text{-}pk}$)) limit of 185 dB re 1 µPa at 750 m from the source (and enforces seasonal restrictions May to August). | Rumes *et al.* (2016) |
| Germany | Impulsive sound must not exceed $SEL_{ss}$ of 160 dB re 1 µPa$^2$s or zero-to-peak sound pressure level ($L_{0\text{-}pk}$) of 190 dB re 1 µPa at 750 m distance from the piling location. | Andersson *et al.* (2017) |
| Netherlands | $SEL_{ss}$ 160 to 172 dB re µPa$^2$s at 750 metres from the sound source for piling between June and December (piling is prohibited in Dutch waters between January and May).<br>Mandatory noise limit 168 dB re 1 µPa²s $SEL_{ss}$. | Andersson *et al.* (2017); Rumes *et al.* (2016)<br>(Heinis *et al.*, 2019) |
| Denmark | Based on frequency weighted SEL levels that must not be exceeded for a fleeing animal with a starting distance of 200m in Denmark.<br>PTS threshold 155 dB re 1 µPa²s for harbour porpoise and 185 dB re 1 µPa²s for harbour seal.<br>Behavioural threshold for harbour porpoise of $SEL_{ss}$ 140 dB re 1 µPa²s. | (Danish Energy Agency, 2022; Tougaard and Mikaelsen, 2023) |
| Taiwan | Applies German decibel limit. | Taiwan Ministry of Environment (2021) |

The requirement for reducing underwater sound during construction within Europe and further afield (e.g. BBCs at Vineyard Wind 1 in the USA (Offshore WIND, 2023)) alongside global growing offshore wind markets (particularly in Asia-Pacific regions (Global Wind Energy Council, 2023)) is likely to drive swift innovation in NMS and NAS. The list of available technologies is expected to evolve rapidly prior to the start of construction of the Project.

## 1.2 Noise Mitigation Systems

NMSs can involve the use of alternative installation methods to impact piling (such as vibro-piling, vibrojet, pre-drilling or blue hammer piling) or optimisation of the piling procedure / use of modifications to the hammer to change the nature of the emitted sound source. The use of each NMS is highly dependent on the specific conditions required for each technology (such as ground conditions, sediment type, soil resistance, tides).

To date, much of the research on NMS and NAS has focused on mitigating the impact of impulsive sound (e.g. piling, UXO, seismic source arrays). However, some technologies such as vibratory hammers emit tonal continuous sound and therefore are not directly comparable to the impulsive broadband sounds generated by impact piling. Further research is needed on the efficacy of noise abatement from the sound emissions and transmission of continuous sound (Bellmann *et al.*, 2020).

### 1.2.1 Alternative installation methods

#### Vibro-piling/vibratory drivers

The pile is vibrated vertically into the seabed, and generates lower peak SPLs than impact hammers (Elmer *et al.*, 2006; Niu *et al.*, 2023), resulting in an at source noise reduction 15-20 dB $SPL_{pk}$ (Elmer *et al.*, 2007b). The noise considered to be non-impulsive, consisting of continuous vibrations and impulsive oscillations. However, although vibratory hammers can be relatively quieter than impact hammers, the cumulative SEL needs consideration due to their continuous operation and the potentially longer time required for pile installation (Oestman *et al.*, 2009). The use of vibro-piling does not completely remove the need for impact piling from the piling sequence; an impact hammer is necessary at the end of the pile installation to verify the stability of the piles (Matuschek and Betke, 2009). This is a system suitable for monopiles and pin piles.

In 2021, a new vibratory pile hammer 'Cape Holland TRIPLE CV-640 VLT-U' was launched, with the potential to significantly reduce underwater sound emissions and speed up the installation of foundations. As part of the research project 'VISSKA' a pilot study was undertaken at the Kaskasi II OWF in Germany (water depths 18 to 26 m). Six monopiles (out of 38 monopiles) were installed using the Cape Holland, to measure, model and assess vibratory piling in relation to installation, noise emission and effects on harbour porpoise (RWE, 2021). Underwater noise measurements showed that vibro-piling resulted in omnidirectional noise radiation, and that the SPL from unmitigated vibro-piling at a distance of several kilometres away from the foundation work was comparable to mitigated impact piling (Bellmann *et al.*, 2024). At Moray West OWF, at sites where there was a period of vibro-piling prior to impact piling of monopiles, no ADD was required (15 minutes ADD and soft start was used at sites with no vibropiling), as the lower noise levels of the vibro-piling were considered sufficient to encourage marine mammals to move away prior to piling.

IQIP recently launched the 'Vibro-Hydrohammer' combination which combines new vibrohammers with its established Hydrohammer impact hammers. The vibratory hammers are used to achieve high speed noise-reduced installation until the point of refusal is reached, which then switches to the IQIP impact hammer to achieve target depth in hard soils (IQIP, 2025; Windpowernl, 2025).

## Vibrojet

Vibrojetting combines vibratory piling with water injection into the sediment, which lowers the resistance of the surrounding soil and results in less energy needed to install the pile. Vibrojetting results in a continuous sound, 30% less power than a vibratory hammer (de Jong, 2023), which would lead to a reduction of the acoustic energy emitted by 30%, corresponding to a SPL reduction of 1.5 dB. In winter 2023, Ørsted successfully tested a jetting technology for installation of three monopile foundations at Gode Wind 3 in Germany (Ørsted, 2024). Ørsted reported a reduction of 34 dB compared to the most commonly used installation method, with underwater sound levels reduced by over 99%.

Vibrojetting has been tested at OWFs, evidencing its effectiveness through practical application. GBM Works completed testing of vibrojetting technology on a the Dutch Hollandse Kust West OWF in March 2025 (Foxwell, 2024). The effectiveness of vibrojetting is dependent on substrate type, suited to more coarse-grained non-cohesive soils such as gravels and sands rather than dense substrate (DOSITS, 2021).

## Pre-drilled pile

Pre-drilling (also known as relief drilling or under-reaming) the hole for a pile can be an effective way of reducing the number of pile strikes required to install a foundation (Oestman *et al.*, 2009), lowering cumulative SELs (more strikes typically results in higher $SEL_{cum}$) and generating continuous noise (Koschinski and Lüdemann, 2020). In pre-drilled piles the pile is initially seated into place with either a vibratory or an impact hammer, the hammer is then removed, and a drill is placed above the hole. A pilot hole is drilled through the pile into the sediment and the drill is then removed after which pile driving can resume as normal. By combining drilling and driving, the method avoids continuous heavy impact hammering, which is a source of intense underwater noise. Pre-drilling is most effective when the seabed sediment is dense (PND Engineering Inc, 2005) and have been used for multiple OWFs to overcome challenging seabed conditions during foundation installation.

Pre-drilled piling has been actively used in OWF projects to date, evidencing its effectiveness. Gwynt y Môr OWF used a specialised relief drill (LD5000) (due to hard geological conditions) to carry out under-reaming (a technique essential to prepare rock sockets for monopile foundations) followed by a combination of driving and drilling to install the 6 m piles (Offshore Energy, 2012). Beatrice OWF in the Outer Moray Firth also used relief drilling when piling encountered boulders and hard clay (hitting early refusal during driving) (Offshore WIND, 2017). A drive-drill-drive method combines impact or vibro-piling with drilling, such that when resistance is met the material inside the pile is drilled out (Koschinski and Lüdemann, 2020). Drill-drive-drill has been applied at Beatrice OWF, North Hoyle OWF, Gunfleet Sands OWF and Teeside Wind Farm, for seabed with mixed layers of sand, boulder clay and sand stone with pile diameters up to 4.7 m (Koschinski and Lüdemann, 2020).

### 1.2.2 Optimisation of piling procedure

#### Pile cushion

Blocks of material can be placed on top of a pile to minimise sound emissions termed 'piling cushions'. Piling cushions extend the duration of the pulse, reducing the corresponding sound emission level (reducing peak SPL) and also results in the shift of the frequency spectrum to lower frequencies (Elmer *et al.*, 2007a; Elmer *et al.*, 2007b). The approach modifies the impact characteristics to reduce noise intensity and change frequency profile. Initial tests demonstrated a 9 dB SEL noise reduction for steel wire, 26 dB SEL for plywood, 8 dB SEL for Micarta and 5 dB SEL for Nylon, although tests were restricted to small diameter piles with no information about the suitability of these materials for offshore conditions.

Two systems have further developed the pile cushion concept offshore (see Table 1-3): the IHC IQIP PULSE (Piling Under Limited Stress Equivalent method) and MENCK Noise Reduction Unit (MNRU). Both have been deployed at OWFs and have shown reductions in sound levels. IQIP's S-4000 Hydrohammer with the add-on IHC IQIP PULSE system is being used in construction of 10 m diameter monopiles at Arcadis Ost 1 in the Baltic Sea (IQIP, 2022) and Baltic Eagle in Germany (IQIP, 2023c) whilst MENCK MHU 4400S hammers and MNRU have been used in the installation of 349 piles in south east Asia (ACTEON, 2024). Available pile cushion technologies, with a summary of methodology, deployment and evidence of effectiveness is summarised in Table 1-3.

**Table 1-3: Available pile cushion technologies.**

| Technology | Methodology | Deployment | Estimated reduction |
|---|---|---|---|
| IHC PULSE (Bellmann *et al.*, 2020) | Two hydraulic pistons positioned between hammer and sleeve, filled with liquid dampening the sound (IQIP, 2023b). | Commercially available, applied offshore.<br>Blow with PULSE twice the duration of conventional blow, increasing the piling efficiency whilst reducing pile fatigue and impact sound (IQIP, 2023b).<br>Deployed on 74 monopiles in various OWFs (IQIP, 2023d). IHC PULSE has been deployed with IQ S-4000 hammer for prototype test at the Arcadis Ost 1 OWF (IQIP, 2023d) and at Baltic Eagle in Germany (IQIP, 2023c). | SEL 6 – 10 dB (IQIP, 2023b)<br>SPL 5 – 12 dB (IQIP, 2023b) |
| MNRU | Metal blocks placed between the ram weight and the anvil which transfers energy to the pile. | Commercially available, applied offshore.<br>MNRU has been applied on >500 piles. Modelling in Steinhagen (2019) predicted a reduction in sound emissions for 6.5 m monopile and 3500 kJ hammer.<br>MENCK MHU 4400S hammers and MNRU have been used in the installation of 349 piles in South East Asia (ACTEON, 2024). | SEL 9 dB (Steinhagen, 2019)<br>SPL 11 dB (Steinhagen, 2019) |

#### IHC HiLo

An adaptive piling technique called HiLo (High frequency Low energy) was developed by IHC IQIP. The HiLo system is a hammer control technology (or mode) integrated into hydraulic piling hammers (like those from IHC IQIP) that precisely adjusts the hammer's blow energy and frequency during pile driving. In contrast to the pile cushion (which employs pulse shaping to reduce noise), the HiLo system reduces noise and pile fatigue by increasing the blow rate whilst reducing the energy per strike (Koschinski and Lüdemann, 2020). This reduces noise and pile fatigue through more frequent but gentler impacts, rather than modifying the impact pulse duration. Offshore tests conducted at an OWF in the North Sea within the German Bight gave results of a reduction of 30 to 40% in strike energy (Anusic *et al.*, 2017), and therefore a reduction in noise levels emitted.

## 1.3 Noise Abatement Systems

NASs represent 'barrier systems' which include both far field (at a distance from the source) and near-field systems (close to source), and include:

- **Air Bubble Curtains** (section 1.3.1): a 'far field' system which creates a layer of air bubbles around the pile that reduces noise transmission through the water column;
- **Pile Casings** (section 1.3.2): a 'near-field' system where casings enclose the pile and minimise noise propagation through wave reflection[1]; and
- **Resonator-Based NMSs[2]** (section 1.3.3): a 'near-field' system which converts the energy carried by acoustic waves into vibrations within their own resonator units, essentially absorbing the noise.

### 1.3.1 Air bubble curtains

An air bubble curtain functions by injecting air into a nozzle hose on the seabed and the air escapes through openings creating a vertical column of buoyant bubbles. Air bubble curtains can be confined, which use air resonators[3] and fabric linings, or unconfined, which consist of a perforated ring/hose on the seafloor encircling the pile and piling vessel. Unconfined bubble curtain systems are generally more cost-effective and practically more effective in low tidal currents where there is less drifting of bubbles, whilst confined bubble curtain systems have been primarily used in shallow inshore areas (up to 15 m depth) with strong/high tidal currents. Whilst confined systems have shown high noise reduction potential, their efficacy offshore depends on many environmental and operational factors and requires individual site-specific assessment. Available bubble curtain systems, with a summary of methodology, deployment and evidence of effectiveness is summarised in Table 1-4.

The BBC and Double Big Bubble Curtain (DBBC) systems are the most often applied technology in OWF construction projects to date. They are applied as standard in Germany (alongside IHC-NMS and HSD) to meet noise emission limits. Sound reductions of up to 16 dB SEL have been achieved (Bellmann *et al.*, 2020). Applications of the BBC/DBBC systems in the German EEZ of the Baltic Sea show a slightly higher sound reduction compared to the applications in the North Sea, considered likely due to lower currents and therefore less drifting of air bubbles.

Dähne *et al.* (2017) studied the effects of constructing the DanTysk OWF (in the German Bight, 80 turbines, 6 m diameter foundations) using passive acoustic monitoring of pile driving noise and harbour porpoise echolocation, with an Acoustic Deterrent Device (ADD) (seal scarer) and two bubble curtains used. The first bubble curtain was a large, circular double- or triple-walled bubble curtain (from Weyres) deployed within a radius of approximately 160 m from the foundation with a circumference of between two and three km, and the second was a large bubble curtain (from Hydro-Technik) which was 500 m long deployed as a circular array, semi-circular arc or linear array. Harbour porpoise occurrence decreased when the seal scarer was engaged, during pile driving and up to five hours after pile driving stopped. The reduced harbour porpoise presence extended out to 12 km, which is less than the 18-25 km reported from other pile driving performed without BBCs, demonstrating BBCs reduced the area of displacement, thus effectively reducing the temporary habitat loss and risk of hearing loss. The two bubble curtains each attenuated the noise by between 7 and 10 dB (received broadband Equivalent Continuous Sound Level ($L_{eq}$)), when used separately, and received 12 dB $L_{eq}$ when used together. Attenuation was most pronounced above 1 kHz, where the pile driving noise at larger distances was comparable to or lower than ambient noise (Dähne *et al.*, 2017).

Recently RWE, in collaboration with Hydrotechnik Offshore has deployed bubble curtains during monopile installation at the Sofia OWF on Dogger Bank; the first time the technology has been used in the UK (Buljan,

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[1]Deflection or bouncing back of sound wave by an object, rather than propagating forward (DOSITS, 2025).

[2] It is acknowledged that, whilst Resonator-Based NMSs are generally given the term 'NMS', they are considered under NAS given the similarity in objectives and approach to reducing sound levels with NAS systems.

[3] Underwater inverted air-filled cavities with combinations of rigid and elastic wall members, fastened to framework to form a stationary array surrounding a noise source (Lee, 2017).

2025). The bubble curtain system was also deployed at He Dreiht in Germany in 2024 during monopile installation. The DBBC was used in combination with two NMS systems (T-NMS-10000 and IQIP PULSE system), with companies suggesting that the combined noise mitigation equipment reduces underwater noise by up to 24 dB (15 dB from the T-NMS-10000 alone) (Buljan, 2024).

**Table 1-4: Available Bubble curtain technologies.**

| Technology | Methodology | Deployment | Estimated reduction |
|---|---|---|---|
| Big Bubble Curtain (BBC) / Double Big Bubble Curtain (DBBC) | Compressed air pumped through nozzle hose (s) laid on the seafloor around the pile position. Builds curtain of bubbles vertically around pile. | Commercially available, applied offshore – including recent application at Sofia OWF (Buljan, 2025).<br>Well-developed system achieving broadband sound reduction.<br>Sound reduction shown in BBC/DBBC in German waters, increased air flow needed in deeper water (Bellmann *et al.*, 2020). Applications at low current have a positive influence on sound reduction since there is less drifting of air bubbles.<br>Dähne *et al.* (2017) demonstrated two BBCs each attenuated the noise by between 7 and 10 dB, when used separately, and 12 dB when used together.<br>Practical considerations include the control of bubble size distribution, generation of a sufficient number of large bubbles to achieve low frequency attenuation, avoidance of bubble leakage caused by currents (which can limit the efficiency of such systems) (Matuschek and Betke, 2009), the number of compressors needed, deck space required and the number/type of vessels required. | BBC 8-15 dB SEL (Bellmann *et al.*, 2020)<br>DBBC 8-18 dB SEL (40 m) (Bellmann *et al.*, 2020)<br>DBBC 15-16 dB SEL (>40 m) (Bellmann *et al.*, 2020)<br>BBC 7-10 dB, when used separately, and 12 dB when used together (Dähne *et al.*, 2017) |
| Grout Annulus Bubble Curtain (GABC) | Compressed air introduced between pile-sleeve and pile. For pile sleeves that do not touch the water surface, air bubbles can escape at the upper edge of the pile-sleeve and rise to the water surface forming a small bubble curtain. Different designs with jacket constructions.<br>GABCs are applicable for post-piled foundations only, but for wind turbine generation (WTG) foundations a similar system placed on the piling template could be used. GABC very sensitive to current (which can distort bubble curtain formation) due to proximity to hammer (where noise intensity and | Commercially available, applied offshore.<br>Used in German waters and have shown a sound reduction for skirt piles in water depths of approximately 40 m, main piles in water depths of approximately 30 m (Bellmann *et al.*, 2020). Hsu (2021) suggested GABC could in theory be deployed at depths suitable for jacket foundations (i.e. 50 m to 80 m). | 2-3 dB SEL (skirt piles) (Bellmann *et al.*, 2020)<br><7 dB SEL (main piles) (Bellmann *et al.*, 2020) |

| Technology | Methodology | Deployment | Estimated reduction |
| --- | --- | --- | --- |
| | turbulence are their maximum), as any instability in bubble density could compromise the immediate attenuation of very high noise levels | | |
| Gunderboom Sound Attenuation System (SAS) | Double-walled sound-dampening fabric barrier used in combination with a bubble curtain confined within the two layers of fabric. | Confined system, more expensive than BBC/DBBC but has been reported as more effective than BBC/DBBC in higher currents or challenging environments (such as in the Knic Arm waterway in which a number of underwater noise attenuation techniques were compared (PND Engineering Inc, 2005)) than unconfined air bubble curtains in attenuating low frequency sounds (PND Engineering Inc, 2005). During a California Department of Transportation (CalTrans) Pile Installation Demonstration Project the Gunderboom SAS reduced sound wave intensity by up to 85 %. | Unknown |
| Little Bubble Curtain (LBC) | Has guiding baffle plates to prevent bubbles from drifting, designed so layers can be stacked telescopically (Wilke *et al.*, 2012) | Tested but not currently commercially available.<br>Tested at the 'Evaluation of Systems for Sound Reduction on an Offshore Test Pile' (ESRa) Project in 2011 (at which five sound insulation systems were tested on a test pile in Neustadt Bay), sound attenuation for the LBC showed sound reduction – however, conditions were not representative for offshore wind (shallow, no currents, pile already anchored) (Koschinski and Lüdemann, 2013; Wilke *et al.*, 2012) | 4.2 dB SEL (Wilke *et al.*, 2012)<br>4 dB $SPL_{pk}$ (Wilke *et al.*, 2012) |
| Mega Bubble Curtain (MBC) | Large diameter pipes (larger than BBC/DBBC) towed to site and deployed, seawater pumped into ballast pipes to sink system and compressed air pumped into pipes to create bubble curtain. After completion, compressed air pumped into ballast pipes to rise system to the surface. | Pilot stage, not currently commercially available.<br>MBC creates even spread of bubbles around curtain, and longer wider pipes can be utilised. No full-scale test in an offshore environment known to date. | Unknown |
| MENCK fire hose system | Small Bubble Curtain (SBC) with vertical pipes attached to piling frame between upper and lower ring. | Tested but not currently commercially available.<br>Used in offshore trial at BARD Offshore 1 OWF in approximately 40 m of water, showed sound reduction (14 dB SEL) (Kumbartzky, 2012). Further development at ESRa Project (Wilke *et al.*, 2012) | 14 dB SEL<br>4.4-5 dB SEL<br>4.5-5.1 dB $SPL_{pk}$<br>(Wilke *et al.*, 2012) |
| Small Bubble Curtain (SBC) | Multiple layers of perforated pipe surround the pile in a ring | Pilot stage, not currently commercially available. | Fixed unit: 12 dB SEL<br>14 dB $SPL_{pk}$ |

| Technology | Methodology | Deployment | Estimated reduction |
|---|---|---|---|
| | formation (Koschinski and Lüdemann, 2013). | Planned to be deployed at the Alpha Ventus OWF in approximately 30 m of water but tidal current reduced effectiveness leading to development of technology to use multiple vertical pipes close to the pile (e.g. Menck SBC) or casings. | (Grießmann *et al.*, 2010)<br>Mobile unit: 11 to 13 db SEL (Zerbst and Rustemeier, 2011) |

### 1.3.2 Pile casings

Pile casings (or isolation casings/pile sleeves) are hollow casings slightly larger than the pile to be driven within it forming a 'sleeve', which creates an acoustic barrier from seafloor to surface. They usually comprise an internal chamber filled with air or closed-cell foam to provide different acoustic impedance than water. The pile is normally driven through the dewatered casing (casing with internal water removed) (Matuschek and Betke, 2009; Oestman *et al.*, 2009) and is generally expected to provide a degree of attenuation equal to, if not higher than, bubble curtains (Oestman *et al.,* 2009).

Table 1-5 presents example pile casing systems, with a summary of methodology, development and evidence of effectiveness. Pile casings to date have been used for monopiles, with the application for pin pile jackets to be confirmed. In Germany, the IHC-NMS has demonstrated broadband sound reduction from over 450 installations at OWFs of between 13 and 17 dB SEL in water depths up to 40 m and currents of less than 0.75 m/s (Bellmann *et al.*, 2020). Figure 32 in Bellmann *et al.* (2020) showed average SEL reduction of over 30 dB for frequencies of more than 1 kHz and between 20 and 25 dB at frequencies between 125 Hz and 500 Hz, thus demonstrating reliable sound reduction across both low and high frequencies.

The most recent full-scale use of the IHC-NMS system is at the EnBW He Dreiht OWF in the German North Sea (IQIP, 2023a), deployed for the installation of 64 monopiles, in conjunction with the IQ6 Hydrohammer and PULSE system though no results in terms of levels of sound reduction are available in the public domain.

**Table 1-5: Available pile casing systems.**

| Technology | Methodology | Examples of deployment | Estimated reduction |
|---|---|---|---|
| MODIGA | Sacrificial casing with internal air bubble ring.<br>This Monopile Offshore Drilling Installation & Grouting Aid (MODIGA) was designed and built to support the drilling machine during installation. An air bubble ring inside the MODIGA results in noise reduction | Deployed at two wind farms in Bay of Biscay in France in 2022 and 2024<br>. | Although no levels of sound reduction are available in the public domain, the reduction is anticipated to be within the ranges as demonstrated for other casing systems such as the BEKA-Shell and IQIP PULSE. |
| BEKA-Shell (Weyres Offshore) | Two half shells that are hydraulically movable and close around the erected pile, with two layered bubble curtains generated between inner wall and the pile, and between the two casings. Mitigation shells penetrate the ground. | Field tested, not currently commercially available.<br>Tested during the 2011 ESRa Project (Wilke *et al.*, 2012), but no known offshore use to date. | 5.9-6.1 dB SEL<br>7.4-7.6 dB $SPL_{pk}$<br>(Wilke *et al.*, 2012) |
| Cofferdam | Steel tubes that surround the pile from seabed to surface so cofferdam is sealed, then interspace completely dewatered by pumps or overpressure; piling takes place in air (Koschinski and Lüdemann, 2013). | Field tested, not currently commercially available.<br>Frequently used for coastal constructions (Caltrans, 2009). Used at the BorWin beta and HelWin alpha wind farm sites for jacket foundations (Koschinski and Lüdemann, 2013; Koschinski and | 13 - 23 dB SEL<br>13 dB $SPL_{pk}$<br>(McKenzie Maxon, 2012) |

| | | | |
|---|---|---|---|
| | | Lüdemann, 2020), Dolwin Alpha OWF in 2013.<br>Test pile carried out at Aarhus Bight showed high sound reduction potential but this is compromised if there is direct contact between the pile and cofferdam (McKenzie Maxon, 2012) | |
| Double Piles/Mandrel | Two concentric steel piles connected by a pile driving shoe which forces no pile-pile contact, to create an air gap between the two piles.<br>Can be double pile with air gap between, filled with concrete or a mandrel double pile (an inner pile removed after pile has final depth). | Field tested, not currently commercially available.<br>Tests have been carried out in the USA in shallow water depths (Reinhall *et al.*, 2015; Reinhall *et al.*, 2016).<br>Successfully addresses propagation of sound waves directly from the sediment (Reinhall and Dahl, 2011a) | Double<br>16.1 dB SEL<br>16.4 dB $SPL_{pk}$<br>Mandrel<br>16.3 dB SEL<br>17.1 dB $SPL_{pk}$<br>(Reinhall *et al.*, 2015) |
| HydroNAS (W3G Marine Ltd.) | Lightweight inflatable fabric creates a column of air around the pile. | Field tested, not currently commercially available.<br>Offshore trial during piling at the Kentish Flat Extension site in 2015, in very shallow water, showed a reduction in overall SEL (W3G Marine Ltd., 2015) | 25 dB SEL<br>(W3G Marine Ltd., 2015) |
| IHC IQIP NMS | Double-walled steel cylinder with sound insulated connections between the outer and inner wall, and an air-filled cavity, with optional confined bubble curtain (Verfuss *et al.*, 2019). | Commercially available, applied offshore.<br>IHC IQIP NMS has been used at OWF projects in German waters with SEL reductions at water depths up to 40 m (Bellmann *et al.*, 2020). Recently deployed for EnBW He Dreiht offshore windfarm in the German North Sea (IQIP, 2023a).<br>Reliable sound reduction in both low and high frequencies; averaged SEL reduction of more than 30 dB for frequencies more than 1 kHz and between 20 and 25 dB at frequencies between 125 Hz and 500 Hz (Bellmann *et al.*, 2020). | 13 - 17 dB SEL (Bellmann *et al.*, 2020) |
| SubSea Quieter | Cylindrical structure made from membrane (different materials woven together and overlaid with a coating mixture of elastomer materials and waterproof sealing foil) deployed around the pile, then filled with air (Audoly *et al.*, 2021; The LIFE-AGESCIC Project, 2023). | Prototype stage, not currently commercially available.<br>Prototype recently tested under controlled maritime conditions in the port of Nantes Saint-Nazaire in France (Greenov, 2024). Showed reduction in sound transmission as frequencies increase: from -20 dB at low frequency to -50 dB at higher frequencies (Audoly *et al.*, 2021). | Reduction in sound transmission: 20 dB at low frequency to 50 dB at higher frequencies (Audoly *et al.*, 2021) |
| Temporary Noise Attenuation Pile (TNAP) | Two pipes with the space partially filled with sound absorbing material and bubbles introduced via a bubble ring at the bottom. | Field tested, not currently commercially available.<br>Has been tested in the USA in 2009 in shallow waters (Reinhall and Dahl, 2011b) and showed differences in the $SEL_{ss}$ and SPL. | 10-15 dB $SPL_{pk}$<br>5-10 dB $SEL_{ss}$<br>(Reinhall and Dahl, 2011b) |

### 1.3.3 Resonator-based NMS

Encapsulated resonator systems comprise an array of resonating units (e.g. small gas-filled elastic balloons or polyethylene (PE) foam elements) deployed around a pile. These systems are similar to bubble curtains but can be adjusted by balloon size. The use of PE foam elements allows high energy absorption by material damping (Koschinski and Lüdemann, 2013). Table 1-6 presents current known resonator-based NMS with a summary of methodology, deployment and evidence of effectiveness of use. HSD systems can show 10-12 dB SEL reduction (Bellmann *et al.*, 2020), but noise reduction occurs mostly at low frequencies (<250 Hz) (Bellmann *et al.*, 2020). HSD have however been successfully used in combination with an optimised BBC to increase overall sound reduction levels and target higher frequencies, demonstrating that a sound reduction of up to 20 dB SEL can be achieved (Bellmann *et al.*, 2020).

**Table 1-6: Available Resonator-based Noise Mitigation Systems**

| Technology | Methodology | Examples of deployment | Estimate reduction |
|---|---|---|---|
| Hydro Sound Damper (HSD) | Net of PE foam elements and balloons filled with air attached to ballasted net surrounding the pile (Koschinski and Lüdemann, 2020). | Commercially available, applied offshore. Has been used in German OWFs to achieve sound reduction (Bellmann *et al.*, 2020). Applied in water depths up to 40 m with piles of 8 m diameter (Bellmann *et al.*, 2020; Koschinski and Lüdemann, 2020). | 10 – 12 dB SEL (Bellmann *et al.*, 2020) |
| AdBM NMS | AdBm NMS consists of hollow chambers which contain trapped air that act as Helmholtz resonators, attached to slats with tension wires. Resonators can be adapted with size, shape and material to control resonance frequency and number of resonators can control sound absorption. | Commercially available, applied offshore in Dutch/American waters.<br><br>Technology tested during the installation of five monopiles at an OWF site in the Netherlands in 2018 (Van Oord *et al.*, 2019), deployed commercially at an OWF in the Netherlands and the USA.<br><br>Attenuation of up to 20 dB $SPL_{pk}$ was measured when coupled with a single BBC (noise was reduced to as little as 161 dB 5th percentile SEL ($SEL_{05}$)), and 8 dB $L_{p,pk}$ and 8 dB SEL measured from AdBM alone (Wochner, 2018). Based on demonstration results and lab testing, the modified system is expected to produce at least an additional 6 dB $SEL_{05}$ of overall reduction. | >6 dB SEL (Wochner, 2018) |

## 1.4 Summary

There are numerous examples of NMS and NAS that have been successfully commercially applied offshore (e.g. IHC PULSE, MNRU, BBC, dBBC, GABC, IHC IQIP NMS, HSD, AdBM NMS) and therefore present feasible mitigation options for the Project. Other techniques are not commercially available but have been pilot tested (MBC, MENCK fire hose system, SBC, many pile casing systems) and therefore could be a more viable option in the future, particularly given the push for NAS in the UK.

Of the commercially available techniques, pile cushions are widely deployed and reduce pile fatigue and noise with proven noise reductions (though some, like MNRU, have more limited frequency effectiveness). Advanced pile cushions such as IHC PULSE require hydraulic hammer integration, adding complexity and cost. Bubble curtains are well developed, widely commercially available, and deployed with good broadband reduction, although their effectiveness can be limited by environmental factors such as currents and water depth. However, newer designs are improving performance under challenging conditions (such as confined bubble curtains, hybrid systems). Pile casing technologies have demonstrated good noise reduction, particularly at low frequencies, but generally involve more complex installation and operational demands.

Resonator-based systems have been applied offshore (but less often than bubble curtains or pile cushions) but often require more site-specific tuning and complex installation. Pile cushion technologies and BBCs/DBBCs in particular have shown very effective and proven reduction in sound levels in offshore environments, as well as resonator-based NMSs. However, the direct applicability of techniques to the Oriel Wind Farm Project is discussed in section 1.5.

It is acknowledged there are some indirect consequences to the application of NMS and NAS and in considering their application, the benefits of such systems must be balanced against the risks. The deployment of these systems often necessitates additional vessels (plus equipment and personnel) or larger vessels to operate the noise mitigation measures (Thompson *et al.*, 2020), contributing both to additional injury and/or disturbance to marine mammals from vessels (or more noise from larger vessels (McKenna *et al.*, 2013)), as well as increased fuel consumption and a higher carbon footprint (shipping contributing increasing global anthropogenic greenhouse gas (GHG) emissions (Winnes *et al.*, 2015)). Furthermore, the implementation of NMS and NAS can lead to an extension of the overall piling duration (even if source levels are reduced), due to the operational constraints imposed by the mitigation measures, such as slower piling rates or additional setup time, which may extend the construction phase and the temporal piling window (Thompson *et al.*, 2020), leading to extended levels of broader-scale chronic or cumulative disturbance over longer timescales. Therefore, procedures will need to be optimised for different design options and areas with different communities and local densities of marine mammals.

## 1.5 Applicability of techniques to Project

As outlined in section 2 of the NIS, all monopile foundation installations will require a combination of piling followed by drilling (drive, drill and grout method), which will minimise the impact piling duration. The monopiles will be lifted into position and installed by driving with assistance from a hydraulic hammer up to a maximum resistance and then by drilling to the required embedment depth. Therefore, in terms of alternative installation methods, the Project has been designed to use the drive-drill method (similar to the pre-drilled pile outlined in section 1.2.1). Other alternative methods are not suitable for the Project due to the coarse sediments, boulder clay and rock required to penetrate on the site.

Whilst some of the NAS systems presented above would be suitable for implementation on the Project at this location, it is considered that the use of a bespoke casing system would be the most suitable as it can support the drilling (drive-drill method) whilst providing noise reduction.

The MODIGA system for the Project will be specifically designed and developed during the detailed design phase of the Project. The application of this system involves placement of the MODIGA onto the seabed into which the sacrificial casing will be lowered. A hammer pile will then be inserted into the MODIGA and the sacrificial casing hammer piled through the unconsolidated sediments.

The system manufacturer states that the MODIGA fitted with an internal air bubble ring can provide underwater noise reduction during piling. Although there are currently no empirical data available to confirm this on a quantitative basis, the principle of introducing an air barrier (similar to a bubble curtain) between the pile and the surrounding structure would theoretically lead to reduced sound transmission. The theoretical reduction in sound transmission arises because air has a much lower acoustic impedance than water or steel, resulting in a reflection of sound energy at the air-water or air-steel interface and reducing the proportion of vibrational energy from the pile transmitted through the air layer into the surrounding water. Therefore, taking both the theoretical considerations and manufacturer’s claims into account, the Applicant considers it reasonable to expect that the use of this system will result in lower underwater noise levels compared to piling without the air bubble system in place. Whilst the amount of noise reduction (in decibel terms or impact ranges) cannot currently be quantified the Applicant is committed to undertake noise monitoring to provide useful data that will inform the use of this system in future developments.

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