Annex O Application for Planning Permission for the Proposed Development ACP Case Ref. ABP-319864-24, RFI Response Annex 5: Noise Mitigation Systems and Strategies – A Targeted Literature Review.

Annex 5 - Noise Mitigation Systems and Strategies – A Targeted Literature Review

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Acronyms

Acronym	Meaning
ABWP2	Arklow Bank Wind Park 2
ACP	An Coimisiún Pleanála
ADD	Acoustic Deterrent Device
BBC	Big Bubble Curtains
BSH	Bundesamt für Seeschifffahrt und Hydrographie
CEFAS	Centre for the Environment, Fisheries and Aquaculture Science
DAHG	Department of the Arts, Heritage and Local Government
DBBC	Double Bubble Curtains
DEFRA	Department of Environment, Food and Rural Affairs
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EPS	European Protected Species
GES	Good Environmental Status
HF	High Frequency
HSD	Hydrosound Damper
JNCC	Joint Nature Conservation Committee
LF	Low Frequency
MMMZ	Marine Mammal Mitigation Zone
MMO	Marine Mammal Observer
MNRU	Menck Noise Reduction Unit
MSFD	Marine Strategy Framework Directive

Acronym	Meaning
NAS	Noise Abatement System
NMS	Noise Mitigation Systems
NPWS	National Parks and Wildlife Service
OWF	Offshore Windfarm
PAM	Passive Acoustic Monitoring
PCW	Phocid Pinnipeds in water
PTS	Permanent Threshold Shift
PULSE	Piling Under Limited Stress Equivalent
RFI	Request for Further Information
ROV	Remotely Operated Vehicle
SEL	Sound Exposure Level
SPL	Sound Pressure Level
T&I	Transport and Installation
TTS	Temporary Threshold Shift
UK	United Kingdom
VHF	Very High Frequency

1 Introduction

1.1 Purpose

Arklow Bank Wind Park 2 (ABWP2) (henceforth referred to as the "Proposed Development") has considered the use and suitability of implementing Noise Abatement Systems (NAS) during offshore construction activities for one of its piling driving scenarios. This review has been prepared in response to the Request for Further Information (RFI) from An Coimisiún Pleanála[1] (ACP), following submission of the Environmental Impact Assessment Report (EIAR). The relevant RFIs requested by ACP are outlined in Table 5.1

Table 5.1 Summary of RFIs relating to NAS

RFI	How the RFI was addressed
"9a(i): 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 observations 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: *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.*	Section 2 of this document provides a comprehensive review of noise abatement measures which could be applied to the Proposed Development. The review provides realistic values for the reduction in sound levels possible from these technologies. The report includes a detailed review on technologies such as bubble curtains, casings (e.g. IQIP Noise Mitigation Screen), resonators (e.g., AdBm Noise Mitigation System), and alternative hammer/piling technologies (e.g. IQIP PULSE damping system). Section 4 details the suitability of the noise abatement measures for the construction of the Proposed Development, including restrictions on their suitability given the site conditions. Section 3 also provides a review of other avoidance and deterrent-based mitigation measures. Together with the review of noise abatement measures, this document provides a comprehensive review of relevant mitigation for the Proposed Development.
9a(ii): 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	It is important to note that Ireland does not currently require any decibel thresholds to be met (although DAHG (2014) references Southall *et al.* (2007), without any explicit

[1] https://www.pleanala.ie/publicaccess/FurtherInformation/319864/319864%20Arklow%20Bank%20Wind%20Park%202%20-%20FI%20request.pdf?r=507921718002098758

RFI	How the RFI was addressed
reduce the level and extent of potential noise impacts arising from the proposed development. Examples include the German 160 dB re 1 µPa²s SELss and 190 dB re 1 µPa SPLpeak thresholds that should not be exceeded at a distance of 750m from a piling site; or the frequency weighted SELcum PTS thresholds (e.g. harbour porpoise 155 dB re 1 µPa²s) that should not be exceeded for a fleeing animal with a starting distance of 200m in Denmark."	statement on what is or is not acceptable) or level of noise reductions to be achieved. Nevertheless, Section 1.3 provides information on approaches to mitigation in other EU jurisdictions (e.g. Germany, Belgium, Netherlands and Denmark). Section 2 reviews technologies to achieve noise reductions, which includes those used in EU jurisdictions. Section 4 discusses the suitability of these measures for the Proposed Development, and identifies suitable noise abatement options.

This report provides a targeted literature review of current methods used to reduce underwater noise emission and propagation from the installation of turbine foundations, and their applicability for the Proposed Development. The review also considers how NAS technologies and international regulatory thresholds vary across national jurisdictions, providing insight into how other jurisdictions have approached underwater noise mitigation in offshore wind development.

The review provides a high-level overview of the suitability and limitations of each technology in relation to site-specific conditions, which include:

- The larger size of monopiles (>7 m monopile diameter);
- The combination of shallow water depth and high tidal current velocity (peak speeds of 2.75 m/s);
- The site-specific factors that affect noise propagation, such as relatively steeply-sloping bathymetry and proximity to deeper water; and
- The influence of modern improvements in design and installation methods. .

It is important to note that this is a desk-based report and should be considered as a literature review focussed on potential for noise emission reduction. It does not account for health and safety feasibility of deploying the systems, cost-effectiveness or commercial viability, or detailed engineering or detailed technical constraints.

1.2 Background

Impact pile-driving (piling) is currently the most common approach for installing turbine foundations for Offshore Wind Farms (OWFs) and other structures, such as substations, piers and harbours (Koschinski and Lüdemann 2013; 2020; Weilgart, 2023). Alternative foundation installation or turbine fixing methods such as gravity-based foundations (Esteban *et al*., 2019), suction buckets (Feld, 2001; Guo *et al*., 2022) or vibratory pile driving (Matuschek and Betke, 2009; Tsouvalas, 2020) are either still under development or only applicable to suitable site conditions.

The sound generated from pile-driving is strongly dependent on a number of factors, including the pile diameter, surrounding water depth, substrate structure and hammer impact energy (Dähne *et al*., 2017). Each strike of the pile produces an impulsive sound, which is characterised by a rapid rise time to maximum pressure followed by a sharp decrease to a minimum pressure, where it then continues as a diminishing, oscillating pressure wave (Amaral *et al*., 2020).

Noise exposure criteria are typically represented by dual exposure metrics including the frequency-weighted Sound Exposure Level (SEL; expressed in decibels (dB) re. 1 µPa²s) and the unweighted peak Sound Pressure Level (SPL; expressed in units relative to 1 µPa in water; ISO 18405, 2017; Juretzek *et*

al., 2021). A hydraulic hammer with an energy of 1000 kJ results in SPLs around 237 dB SPL re 1 µPa at 1 m with a predominant frequency bandwidth between 100–1000 hertz (Hz; Heldebrand, 2009; Rako-Gospić and Picciulin, 2019). Current hydraulic hammers for monopile installation have a maximum energy of up to 6,600 kJ (IQIP, 2026) and it is expected that larger hammer energies will be developed in the future (Moscoso *et al*., 2025).

The frequencies of underwater noise emitted during pile-driving overlap with various marine mammal species' hearing and vocalising ranges, which can lead to direct and indirect impacts (Duarte *et al*., 2021). The noise produced during installation can result in disturbance and/or displacement responses for marine mammals, and could potentially cause instantaneous and/or cumulative auditory injuries (permanent threshold shift, or PTS). These effects include masking of biologically important sounds, behavioural responses, and/or physiological impacts such as hearing impairment including a temporary threshold shift (TTS) or PTS in hearing (Southall *et al*., 2007; Popper *et al*., 2014; Erbe *et al*., 2016) or other auditory impacts.

Noise exposure criteria have been designed to define thresholds for underwater sound that may cause auditory injury/PTS and TTS in marine mammals. Table 5.2 presents the onset thresholds for PTS and TTS in different marine mammal hearing groups, as defined by Southall *et al*. (2019). These thresholds are also used in EIAR Volume II Chapter 11: Marine Mammals (Revised March 2026), as presented in Table 11.18.

Table 5.2 PTS and TTS onset thresholds for marine mammals in different hearing groups exposed to impulsive noise (Source: Southall *et al.* 2019). Hearing group outlines species and species groups that may be recorded in Irish waters.

Hearing Group	PTS Thresholds		TTS Thresholds	
	Peak SPL (dB re 1 µPa)	**SEL (weighted, dB re 1 µPa²s)**	**Peak SPL (dB re 1 µPa)**	**SEL (weighted, dB re 1 µPa²s)**
Low-frequency (LF) cetaceans (Baleen whales)	219	183	213	168
High-frequency (HF) cetaceans (Dolphins, toothed whales, beaked whales, bottlenose whales)	230	185	224	170
Very high-frequency (VHF) cetaceans (True porpoises)	202	155	196	140
Phocid pinnipeds in water (PCW) (True seals)	218	185	212	170

All OWF projects where underwater noise has the potential to impact marine mammals should carry out underwater noise modelling to inform the consenting process. Ranges (distance from piling source) for TTS and PTS onset are dependent on the project's location, environment, installation method and size of piles, as well as the species group of concern.

Different underwater noise mitigation strategies can be implemented to reduce the risk of injury and disturbance to marine mammals. Common mitigation measures are avoidance and deterrent based, these include the use of Acoustic Deterrent Devices (ADDs), soft starts, ramp-ups and marine mammal monitoring to reduce the risk of mammals being present in the vicinity of the pile. In cases where impact ranges are greater than those that can be mitigated with these common mitigation measures, additional measures such as noise abatement systems (NAS) may be required.

There are a number of NAS which are designed to reduce underwater noise during offshore construction activities, particularly from pile driving. NAS are typically grouped into two categories: primary noise reduction and secondary noise reduction.

Primary noise reduction aims to reduce sound emissions at the source, for example using systems such as the MENCK Noise Reduction Unit and IQIP PULSE® technology. Secondary noise reduction aims to reduce sound propagation through the water column and is typically achieved through barriers of varying types (e.g. the Hydro-Sound Damper or bubble curtains) (Bellmann *et al.*, 2020).

More details on NAS are presented in Section 2. NAS are not universally applied and can have limitations in terms of environmental conditions, commercial readiness, or amount of noise reduction that can be achieved. For example, the Developer's Dogger Bank A, B and C projects in the UK, which are monopile projects currently in construction, have not applied NAS.

More details on avoidance and deterrent-based mitigation are presented in Section 3.

1.3 International Noise Mitigation Strategies

Noise mitigation strategies vary significantly between national jurisdictions because the legal requirements and guidance that drive assessments and mitigation differ fundamentally. Individual countries requirements are guided by country-specific species presence, abundance and diversity, the local environment (water depths, metocean, soil conditions etc.), and what is practically achievable given these factors.

In Germany and Belgium, a Source-and-Threshold approach is adopted, where strict decibel limits often mandate the use of NAS for high-noise activities. However, other countries such as the UK, Ireland and Denmark adopt a Receiver-and-Exposure approach, where assessments are based on predicted exposure at the receptor level, using site-specific acoustic modelling. Countries that apply the Receiver-and-Exposure approach such as Ireland apply adaptive, impact-based strategies where noise reduction such as NAS is only required to avoid significant impact. Under this approach, mitigation will be appraised in terms of environmental impact on a project-by-project basis.

In parallel with international standardisation efforts, countries have developed or are in the process of implementing regulatory frameworks to manage underwater noise from pile-driving. Guidance for minimising the risk of injury to marine mammals from offshore activities has been published in the UK (JNCC, 2010), Ireland (NPWS, 2014), Denmark (Danish Energy Agency, 2022), Germany (BSH, 2019) and the United States America (BOEM, 2019).

The following section outlines the different approaches to underwater noise mitigation across several different jurisdictions.

To note, several countries included below are part of the European Union and therefore have to comply with European legislature in addition to national legislature. Under the European Marine Strategy

Framework Directive (MSFD), 'good environmental status' (GES) is achieved when introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment' (European Commission, 2017).

1.3.1 Ireland

In Ireland, the Department of the Arts, Heritage and Local Government (DAHG), published guidance in 2014 to manage the risk that anthropogenic sound-sources pose to marine mammals in Irish waters (DAHG, 2014). This guidance presents a staged process towards managing risk but does not enforce any specific process to restrict noise impacts nor state explicit decibel limits . It offers suggestions for mitigation that can be applied to projects, including pre-piling monitoring for marine mammals and a soft start and ramp up process. In section 4, the guidance details various management options for regulatory authorities to consider while approving any marine licences.

The DAHG guidance (2014) presents a number of risk minimisation measures which can be applied where appropriate, including:

- "A6.3. Incorporate the use of clear "ramp-up" (i.e., "soft-start") procedures, whereby sound energy input to the marine environment is gradually or incrementally increased from levels unlikely to cause significant behavioural impact on marine mammals to the full output necessary for completion of the activity.
- A6.4. Incorporate the use of fully enclosing or confined bubble curtains, encircling absorptive barriers (e.g., isolation casings, cofferdams) or other demonstrably effective noise reduction methods at the immediate works site, in order to reduce underwater sound propagation from on-site operations. As stated in DAHG (2014), studies have shown that such methods can provide a significant reduction in sound input to the wider aquatic environment in the order of 10-30 dB.
- A6.5. Use trained and experienced marine mammal observers (MMOs) to provide effective means of detecting marine mammals in the vicinity of coastal and marine plans or projects."

Section 4.3.3 of the DAHG guidance (2014) gives detailed technical guidance on pile driving. The Developer can comply fully with this guidance, though is of the view that guidance item number 3, regarding pile driving activities only commencing in daylight hours is overly restrictive and does not reflect the adoption of PAM as an industry standard pre-start monitoring/mitigation measure. This may be related to the fact the guidance has not been updated since 2014.

1.3.2 United Kingdom

Similar to Ireland, no decibel limit currently exists in the United Kingdom (UK), although underwater noise may be one factor considered within the UK marine licensing system (Convention on Biological Diversity, 2016). The Department of Environment, Food and Rural Affairs (Defra) commissioned a feasibility assessment and pilot programme titled "A noise limit for offshore wind pile driving", aimed at evaluating the feasibility of introducing a decibel-based noise limit for offshore wind pile driving in English and Welsh waters (Tetra Tech RPS Energy Limited and Seiche, 2024). As part of the study, modelling was conducted to assess the effectiveness of NAS. The findings concluded that whilst the German limit (160 dB SEL_{ss} at 750 m) is technically achievable, it is scenario dependent and not universally attainable for future UK projects due to site-specific environmental variables. Therefore, a variable decibel limit would need to be applied to English and Welsh waters to allow developments to continue. It is also emphasised that a combination of NAS solutions is likely essential, especially for large, deep-water piles.

In January 2025, the Joint Nature Conservation Committee (JNCC), Natural England (NE) and the Centre for the Environment, Fisheries and Aquaculture Science (CEFAS) published a joint position statement on the use of quieter piling methods and NAS when installing offshore wind turbine foundations (JNCC, 2025). This joint position statement comprises Statutory Nature Conservation Body recommendations and has not been formally adopted or enforced. It recommends that regulators bring in a requirement that European Protected Species (EPS) licences for disturbance to cetacean species from offshore wind pile

driving should only be accepted if quieter installation methods and/or NAS are considered, to inform Test 2 of the application process, that there are no satisfactory alternatives. It is important to note that an EPS Licence application is a separate process from planning consent, Environmental Impact Assessment, and Appropriate Assessment, with its own legal tests and requirements under the Conservation of Habitats and Species Regulations 2017 and the Conservation of Offshore Marine Habitats and Species Regulations 2017.

In Ireland, the equivalent process is a derogation licence for Annex IV species under the European Communities (Birds and Natural Habitats) Regulations 2011, for which separate legislative offences, tests, guidance and case law apply. For the Proposed Development, an Annex IV Risk Assessment (Annex IV Risk Assessment (RFI March 2026)) has been prepared to address the potential requirement for a derogation licence in accordance with Irish legislation.

Furthermore, in January 2025 the Marine Management Organisation in the UK published its policy paper "Reducing Marine Noise", which outlines that developers are now expected to demonstrate best endeavours to reduce underwater noise. This includes the use of primary and/or secondary noise reduction measures, such as NAS (Marine Management Organisation, 2025). The paper also notes that the UK Government intends to consult on a future offshore wind piling noise limit. Evidence to inform this process will be collected through a pilot programme undertaken in collaboration with offshore wind developers during piling activities.

1.3.3 Denmark

The Danish Energy Agency have published guidelines (Danish Energy Agency, 2022) for managing underwater noise during the installation of impact or vibratory driven piles. They include a required prognosis scenario section which asks the developer to consider noise impact reduction methodologies during a planned pre-construction case, prior to the construction permit application. The developer may choose to use NAS or not but must show that the planned activity complies with the relevant PTS thresholds highlighted in section 2 of their guidance. The guidance also requires that TTS and behavioural effects are evaluated, however it is only PTS thresholds which are not to be exceeded.

These PTS thresholds follow those presented in Southall *et al.* (2019). Thresholds are species-specific, covering the six species of marine mammal common to Danish waters and four relevant frequency hearing groups (low frequency cetaceans, high frequency cetaceans, very high frequency cetaceans, phocid carnivores in water), and were derived from Southall *et al*. (2019) and reviewed in Tougaard (2021). Of these six species, four (harbour porpoise, minke whale, harbour seal and grey seal) were also identified as having a likely presence within the vicinity of the Proposed Development. All the marine mammal species potentially present in the vicinity of the Proposed Development fall under the one of the four frequency hearing groups adopted in the Danish guidelines. The guidelines specify that a radial distance from the piling, r_{safe}, should be presented over which there should be no animals of these species, and therefore no risk of PTS (i.e. modelling PTS range is less than r_{safe}), and which can be mitigated through the use of an ADD (unless r_{safe} is low, i.e. <200 m).

The guidance refers to three reviews (Koschinski and Lüdemann, 2020; Merchant and Robinson, 2020; Bellmann *et al*., 2020) of available NAS technologies as were accessible at the time of writing the guidance (Danish Energy Agency, 2022). The guidance notes that acoustic measurements must be taken during pile driving at an appropriate number of prognosis locations and must remain within the approved prognosis (PTS range is within the established r_{safe}) to avoid non-compliances.

1.3.4 Belgium

To comply with MSFD requirements, Belgium adopted an 'interim' criterion for impulsive noise of a 'maximum zero to peak noise level (Lz-p) [equivalent to SPL peak] of 185 dB re 1 µPa at 750 m from the

source' (Anonymous, 2012 as cited in Rumes *et al*., 2016). However, noise mitigation is only implemented if this noise limit is exceeded (Rumes *et al*., 2016) and not all windfarm developments monitor noise during installation, but instead the noise is inspected ad hoc. Belgium also has seasonal piling restrictions where there is no piling from 1st January to 30th April to protect sensitive life-history periods for key species such as harbour porpoise and seals (Rumes *et al*., 2016; Verfuss *et al*. 2016).

1.3.5 Germany

Germany's regulation authority, Bundesamt für Seeschifffahrt und Hydrographie (BSH), was the first country to establish a legal dB limit, in 2013. The limit, as determined in 2013, is 160 dB re 1 μPa^2s SELss or 190 dB re 1 µPa SPL peak, and must be complied with at a distance of 750 m from the pile installation location (Koschinski and Lüdemann, 2013). Since 2013, licences for pile driving are only granted if the anticipated generated piling noise is below this legal limit (Merchant and Robinson, 2020). These limits have been adopted in marine licences for some projects in other jurisdictions, such as Taiwan where potential OWF installations are a concern for the critically endangered Taiwanese white dolphin (*Sousa chinensis taiwanensis*; Liu *et al*., 2018). Merchant (2019) reviewed the German approach and concluded that it is the most effective noise management model available at the time. However, as pile sizes and hammer energies have increased significantly since 2013, the German noise limit is becoming increasingly difficult to achieve in German waters, and is not always met even with the deployment of multiple NAS (Tetra Tech RPS Energy Limited and Seiche, 2024) and the relatively conducive waters to the effective utilisation of NAS. Therefore, other jurisdictions such as the UK are considering alternatives to adopting already established limits such as the German limit, to reflect their specific environmental considerations and avoid unnecessarily excessive restrictions (Tetra Tech RPS Energy Limited and Seiche, 2024).

1.3.6 Netherlands

The Netherlands requires mitigation for piling and geophysical survey activities on a case-by-case basis (Anonymous, 2012b as cited in Rumes *et al*., 2016). An example presented in Rumes *et al*. (2016) showed that they set a noise restriction at Borssele OWF at 160-172 dB re 1 μPa^2s SEL_{ss} at 750 m from the source. This project set up continuous noise monitoring and had a seasonal piling restriction between 1st January and 31st May to protect sensitive life-history periods for key species such as harbour porpoise and seals (Rumes *et al*., 2016; Verfuss *et al*. 2016). More recently, the Ijmuiden Ver Alpha project received consent with an impulsive noise limit during piling work of 164 dB re 1 μPa^2s SEL_{ss} at 750 m from the source (RVO, 2023).

1.3.7 Poland

Although an official, regulatory, legislative or other guidance reference source document was not found, recent Polish OWFs (including but not limited to Baltica 1, Baltic Power and BC-Wind) have had conditions applied by the Regional Director for Environmental Protection in Gdansk requiring calculation of TTS ranges for the key species present in the region, specifically the VHF and PCW categories from Southall *et al*. (2019). Although specific conditions for fish species have been included for previous developments, these have been omitted for more recent developments (e.g. BC-Wind).

The permission for development requires that the noise produced during piling does not exceed, at a distance of 11 km from the piling site, weighted TTS impact ranges of 140 dB re 1 μPa^2s SEL_{cum} for harbour porpoise (VHF-weighted) and 170 dB re 1 μPa^2s SEL_{cum} for seals (PCW-weighted). It is understood the origin of this distance is derived from the radial distance over which not more than 0.33% of the harbour porpoise population would be exposed to noise sufficient to elicit TTS, and can theoretically flee from an ADD (MEWO, 2022; SAMBAH, 2016).

The wording of the requirements makes it clear that that NAS is expected to be required to meet this threshold.

1.4 Summary

Based on the reviewed literature, it is evident that the regulatory system for underwater noise and associated approaches to underwater noise mitigation vary significantly across national jurisdictions. There is no “one size fits all”, in terms of a common limit used, or indeed a common approach to setting a limit. Each jurisdiction appears to have taken an approach that is specific to its interpretation of its own unique regulatory requirements and presence of sensitive species.

It is important to note that Ireland does not have any regulatory requirements for threshold limits that need to be met and/or the implementation of underwater noise reduction for piling during offshore wind construction, unlike some of the other jurisdictions reviewed (e.g., Germany and Belgium). Without a clear regulatory framework, there is no formal obligation to meet a particular noise threshold. Given that international approaches are not standardised, there is no obvious international approach that could or should be applied in Ireland. Instead, Ireland advocates a risk or impact assessment-based methodology, in which mitigation measures are applied as appropriate. The EIAR Volume II, Chapter 11: Marine Mammals (Revised March 2026) presents an impact assessment in which appropriate mitigation measures were identified to avoid a significant effect in EIA terms, without the need for further noise reduction measures such as NAS. In addition, an Annex IV risk assessment has been prepared for the Proposed Development (Annex IV Risk Assessment (RFI March 2026)). Both these assessments rely on the appropriate mitigation measures that will be implemented through the MMMP (Volume III, Appendix 25.2: (Revised March 2026)), which are in accordance with DAHG (2014) (though see Section 1.3.1 for the Proposed Development’s justification on the use of PAM).

Similar to the Irish approach, the UK does not prescribe a fixed noise limit. The recent feasibility study commissioned by Defra found that the German limit (160 dB SEL_{ss} at 750 m) is not universally attainable in UK waters due to site-specific variability. As a result, the study recommended the use of site-specific thresholds based on local conditions. This outcome reinforces the idea that a “one size fits all” limit may not be appropriate in Irish waters. Benefits of this approach are that it produces an accurate reflection of the actual impact, tailored to the important species, and readily allows for new research and modelling methods to be incorporated.

Germany’s regulations provide thresholds at a specified distance which have shaped expectations around the use of NAS for offshore wind projects. However, the German thresholds are becoming increasingly more challenging to meet due to increasing pile sizes and hammer energies. Both the German and Belgian approaches rely on fixed noise limits that relate only to the noise from the sound source at a fixed distance, and so does not take into account any avoidance or deterrent based mitigation which offer additional protection from auditory impacts through the marine mammal fleeing response. Furthermore, the focus of these noise limits are harbour porpoise, but the limits do not take into account their hearing sensitivity in that they are not weighted to harbour porpoise hearing. Furthermore, a limit focussed on harbour porpoise may be appropriate when that is the only cetacean species regularly present in national waters, as is the case in Germany and Belgium; however, this approach may not be appropriate for Irish waters where there is greater species richness, including multiple cetacean and pinniped species from varying hearing groups and so different auditory sensitivity thresholds. Similarly, the Polish approach applies a fixed noise limit approach, with the main distinction being that the distance is derived from data relating to harbour porpoise density in the Baltic Sea. This approach may be oversimplistic in an Irish context as it does not account for site-specific populations, noise propagation or species-specific responses.

The Danish guidelines are unique in their use of species-specific auditory impact thresholds (from Southall *et al*., 2019) as a noise limit. These are the thresholds that have been used in the underwater

noise modelling and EIAR for the Proposed Development. Specifically, the Danish guidelines use the thresholds for PTS, which is aligned with the UK and many other jurisdiction's approach to define auditory injury (Volume III, Appendix 11.5: Temporary Threshold Shift (TTS) Position Paper - SMRU Consulting (RFI March 2026)). This approach provides flexibility in the choice for mitigation measures, including the option to not use NAS, provided that they are compliant with the approved prognosis. The Danish approach also allows the inclusion of avoidance and deterrent based mitigations, whilst the noise-threshold approaches of Germany and Belgium do not, which is considered a limitation.

The Competent Expert considers that the Danish guidelines are the most appropriate for the Proposed Development because:

- They use the threshold for PTS, which is the most widely-accepted and evidence-supported definition of auditory injury in marine mammals (Volume III, Appendix 11.5: Temporary Threshold Shift (TTS) Position Paper - SMRU Consulting (RFI March 2026));
- The PTS thresholds in the Danish guidelines are based on Southall *et al* (2019), which was used in the Proposed Development's EIAR and therefore most directly aligns with the Receiver-and Exposure approach used in the EIAR;
- The Danish guidelines provide thresholds for each marine mammal hearing group. Therefore, they are more appropriate in regions where species from multiple marine mammal hearing groups are frequently present, such as in Ireland. In contrast, thresholds based solely on harbour porpoise may not provide relevant levels of protection for other species e.g. low frequency cetaceans such as minke whale;
- The Danish guidelines allow for consideration of avoidance and deterrent-based measures, such as marine mammal monitoring, ADDs and ramp-ups, which are used in Ireland as mitigation measures to reduce the risk of animals being present in the area immediately around the noise source; and
- The thresholds within the Danish guidelines are achievable at the Proposed Development. As shown in Figure 5. 1and Figure 5. 2, the characteristics of Danish waters, in terms of the presence and proximity of deeper water, are far more comparable to the conditions at the Proposed Development on the Irish east coast when compared to German waters. Given the relationship between sound propagation and deep water, it is therefore logical that the Danish thresholds would be more appropriate than absolute sound level-based thresholds that must be met in Germany or Belgium.

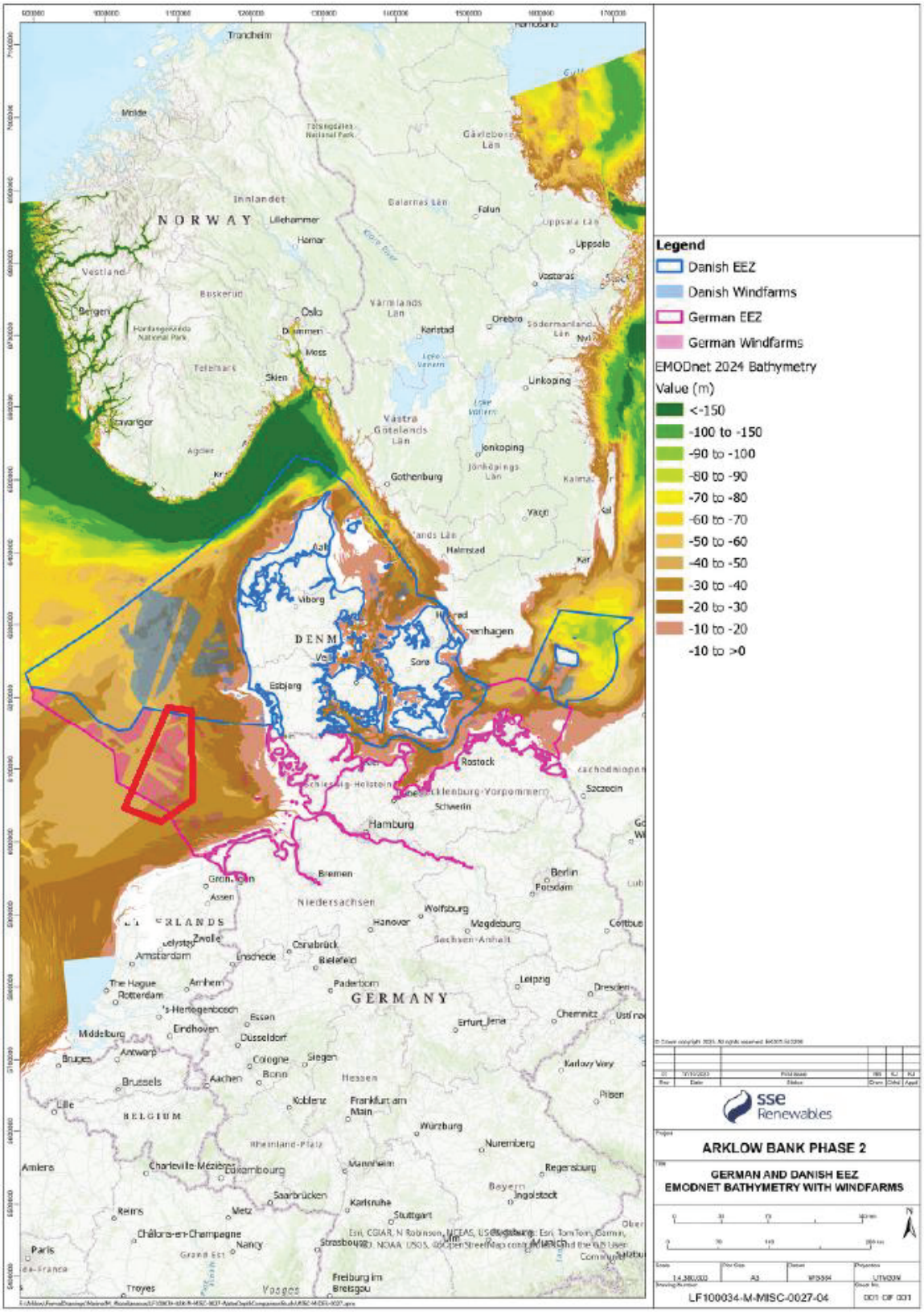


Figure 5. 1 German and Danish Exclusive Economic Zone (EEZ) EMODNET Bathymetry with windfarms.

Note: Area encompassing German sites in active development is outlined in red. Windfarm sites shown outside of this are not active leases.

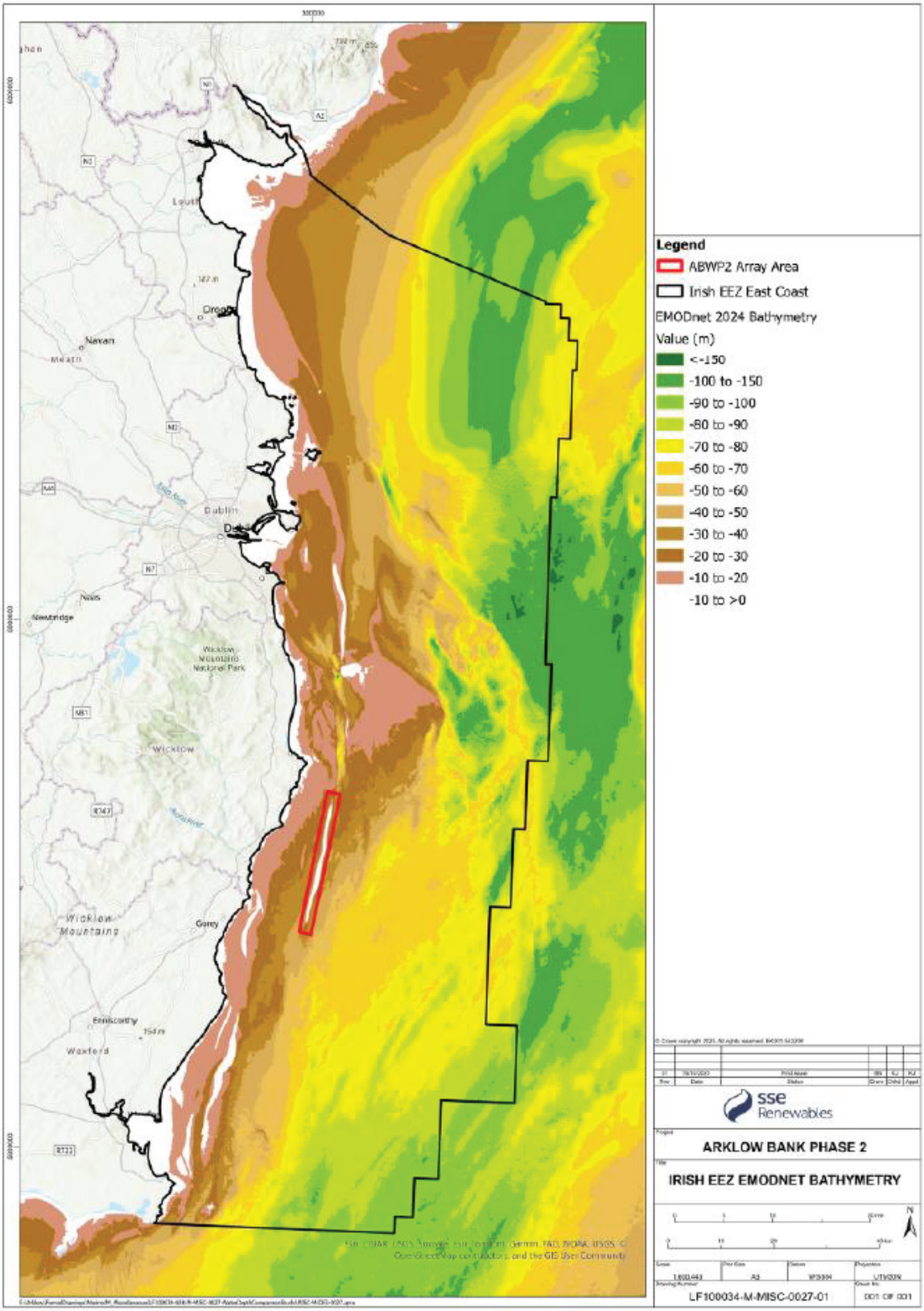


Figure 5. 2 Irish East Coast EEZ EMODNET Bathymetry with Array Area

2 Literature Review of Noise Abatement Systems

There are a range of NAS which are commercially available and in development to reduce underwater noise during offshore wind construction, particularly during impact pile driving for monopile and jacket foundations. NAS can be differentiated into two categories: primary and secondary mitigation measures. Primary measures reduce noise emissions at source, through modifications of the piling process, whereas secondary measures reduce noise propagation through the water during piling (Defra, 2025).

For the purpose of the review, the following terms for broad types of NAS have been used:

- Bubble curtains (secondary mitigation measures) including Big Bubble Curtains (BBC), Double Bubble Curtains (DBBC) and enhanced Bubble Curtains (eBBC);
- Near pile systems (secondary mitigation measures) including Hydrosound Damper (HSD), AdBm noise mitigation system, IQIP Noise Mitigation Screen;
- Dewatered cofferdams (secondary mitigation measures); and
- Alternative hammers (primary mitigation measures) including vibro-hammer, pile cushioning (inc. low noise hammers IQIP PULSE and MENCK MNRU), and EQ technology.

In practice, NAS deployment during monopile installation has typically used bubble curtains, isolation casings and/or HSD (Weilgart, 2023). For jacket foundation installation, bubble curtains remain the only suitable technology, except for one HSD-prototype test (Verfuss *et al*., 2019) which has not been commercialised at the time of this review. These systems are considered by German authorities as state-of-the-art systems for water depths up to 40 m (Koschinski and Lüdemann, 2020; Verfuss *et al*., 2019). All these systems provide a sound barrier around the piling location and can be used in conjunction with one another to enhance performance.

Whilst NAS can be used to reduce noise, there are operational considerations to take into account. It is argued that using NAS increases the overall piling duration, through additional deployment time and waiting for suitable environmental conditions (CEFAS, 2025). Furthermore, some NAS require additional vessels (CEFAS, 2025), which can add to existing vessel-borne impacts and considerations. It is also highlighted that NAS are less proven in deeper waters, but NAS strategies for deeper waters will likely increase in terms of cost and complexity when compared to shallow waters.

Bellman *et al*. (2020) reviewed noise levels produced during piling, with and without noise mitigation measures, from 21 offshore windfarms in German waters. Table 5.3 (taken from Bellmann *et al*., 2020) highlights the range in zero to peak SPL (dB re 1 µPa) and broadband SEL (dB re 1 μPa^2s) measurements at 750 m from monopile installations of various pile diameters when NAS is not implemented. These levels fall between 150 re 1 μPa^2s SEL_{ss} at 750 m from the source for the smallest piles to up to 182 dB re 1 μPa^2s SEL_{ss} at 750 m for piles over 8 m in diameter (Bellmann *et al*., 2020, blow energy not specified).

Based on achieving acceptable noise levels with respect to the German standard for example, the key question surrounding the use of NAS in the field would therefore be the ability of the NAS to reduce noise by at least SEL of 10-20 dB re 1 μPa^2s (Nehls *et al*., 2007). Since achieving the SEL limit typically requires a greater dB reduction than the SPL limit, NAS measures are generally focused on meeting the SEL threshold. Therefore, it can generally be assumed that if the required dB reduction is achieved for SEL, the SPL limit will also be met.

The following sections provide a detailed review of the different NAS, particularly highlighting their noise reduction capabilities, efficacy and current state of knowledge.

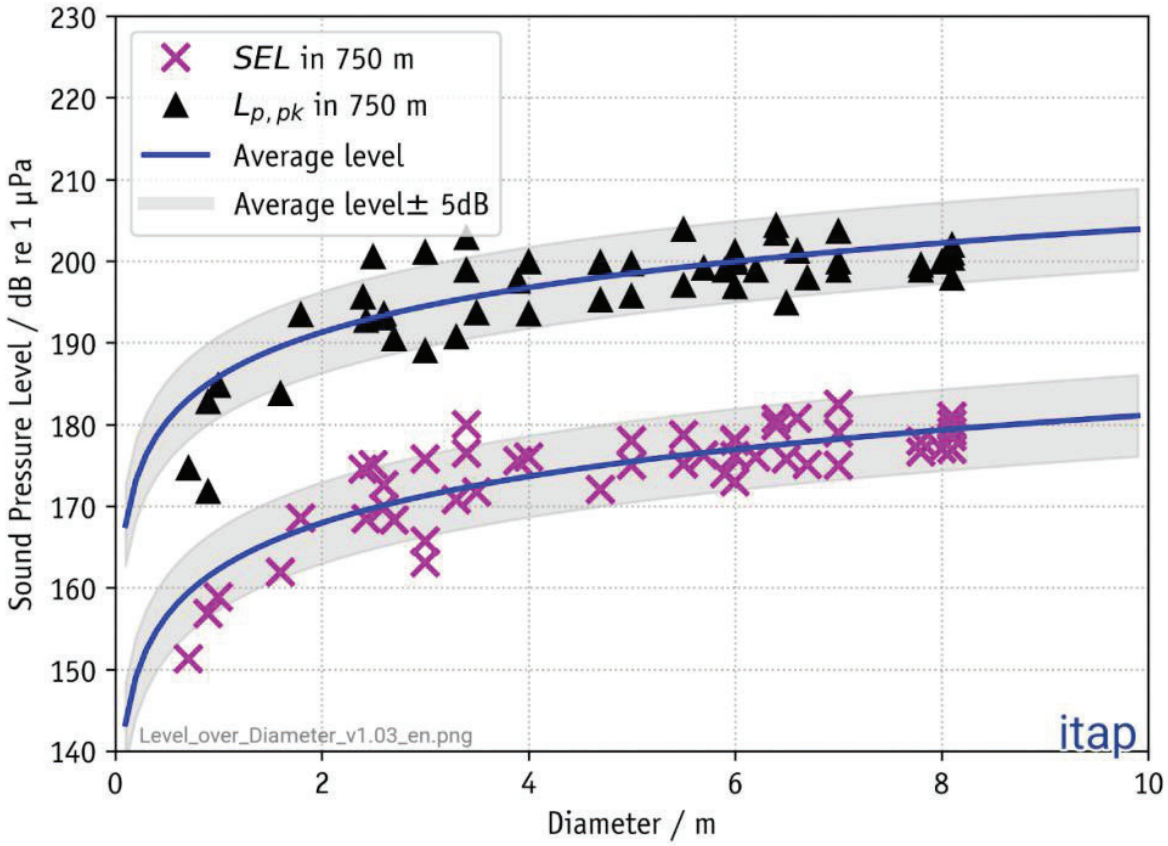


Figure 5.3 Measured zero-to-peak Sound Pressure Levels (Lp, pk) and broadband Sound Exposure Levels (LE resp. SEL05) at various diameter monopile installations. No noise abatement systems were used during these measured activities. SEL05 resp. L05: exceedance level of the single blow analysis of the Sound Exposure Level, which was exceeded in 5% of all single strikes over the considered time interval. Source: Bellmann *et al.* (2020).

2.1 Bubble Curtains

Bubble curtains comprise a hose that is deployed around a piling location and releases a steady stream of air bubbles that provide sound attenuation. There are two types of bubble curtains which have been used as noise mitigation measures for impact pile driving: big bubble curtains (BBCs) and little bubble curtains. BBCs of some configuration have traditionally been the most commonly used NAS approach for OWF foundations (Convention on Biological Diversity, 2016; DAHG, 2014; Koschinski and Lüdemann, 2013; 2020).

In contrast, little bubble curtains have been tested at the pilot stage (Koschinski and Lüdemann, 2013). At the time of testing they were reported to be limited to shallow waters and low tidal current (Koschinski and Lüdemann, 2013). The Competent Expert is not aware of little bubble curtains being used for full-scale projects since, nor further updates on their restrictive environmental limitations. Therefore, they are not considered viable for the Proposed Development, and have not been discussed further.

2.1.1 Big bubble curtains

BBC technology includes a flexible hose system, which lies on the seabed surrounding the noise source, and is connected to a support vessel equipped with special compressors designed to press air into the hose system (Bellmann, 2014). The compressed air escapes from special nozzle openings in the hose

and in turn creates a continuous flow of bubbles across the water column surrounding the pile. Noise propagating through the water is therefore reduced by being scattered, reflected, and absorbed by the air bubbles (Koschinski and Lüdemann, 2020; Zhu *et al*. 2023). Noise reduction depends on the air supply (volume, pressure and size of bubbles), nozzle hose configuration and length, water depth, subsea soil conditions and current direction and speed (Weilgart, 2023), with operational factors varied to suit local conditions. BBC systems can be designed to have either a single (BBC) or double (DBBC) row of hoses spaced at least the water depth apart from each other on the seabed.

BBCs are independent from the foundation design and installation vessel. They require a separate vessel which adds additional non-impulsive noise (e.g. vessel engine and compressors) into the marine environment. In suitable environmental conditions, bubble curtains are a proven solution for both monopiles and jacket foundations.

Another benefit of BBCs is that it is an effective method of mitigating noise that re-enters the water column at distances up to 150–160 m from the pile driving ("ground-coupling effect"; Weilgart, 2023), which can be a problem in particularly wet soil types. BBCs are most effective at higher frequencies (e.g., >500 Hz), therefore making them particularly effective in reducing impacts to harbour porpoise (CEFAS, 2025). Acoustic monitoring that has been conducted by Nehls *et al*. (2016) showed the use of a BBC for pile driving for OWF foundations has reduced noise levels by between 9–13 dB. Results from these data conclude that use of NAS reduced spatial and temporal disturbance effects for harbour porpoise (*Phocoena phocoena*) by up to 90%. A large body of evidence indicates that use of even a single bubble curtain can reduce noise by at least 10 dB (see Table 5.3) in both shallow and deeper water, under optimal system configuration and environmental conditions.

BBCs can be used effectively within appropriate environmental limits i.e. water depth and current speed, to limit bubble dispersal and so effectively reduce underwater noise propagation (Merchant and Robinson, 2020). At greater depths (>40 m), the implementation of bubble curtains becomes increasingly difficult due to the dispersion of bubbles in the water column. Additionally, locations with strong currents (>0.75 m/s) or sub-optimal configurations of components (e.g. compressors and nozzle hoses) contribute to a decrease in noise reduction (Bellmann *et al*., 2020).

Table 5.3 Achieved noise reduction for the sound exposure level (dB re 1 µPa²s) using single or double big bubble curtains during monopile installations across various water depths. Source: Bellman *et al.*, 2020).

System configuration	ΔSEL [dB]
Single Big Bubble Curtain – BBC (> 0.3 m^3/(min*m), water depth <25 m)	11 ≤ 14 ≤ 15
Double Big Bubble Curtain – DBBC (> 0.3 m^3/(min*m), water depth <25 m)	14 ≤ 17 ≤ 18
Single Big Bubble Curtain – BBC (> 0.3 m^3/(min*m), water depth ~40 m)	7 ≤ 9 ≤ 11
Double Big Bubble Curtain – DBBC (> 0.3 m^3/(min*m), water depth ~40 m)	8 ≤ 11 ≤ 13
Double Big Bubble Curtain – DBBC (> 0.4 m^3/(min*m), water depth ~40 m)	12 ≤ 15 ≤ 18
Double Big Bubble Curtain – DBBC (> 0.5 m^3/(min*m), water depth >40 m)	~ 15 – 16

2.2 Near-pile systems

Near-pile systems are designed to reduce underwater noise close to the pile. The systems typically use resonators or casings to reduce noise, and surround or are directly attached to the pile. An isolation casing is a shell-in-shell system around the pile in which a shielding effect of the casing reduces the radiated noise.

2.2.1 Hydrosound damper

HSD systems are designed to reduce continuous and impulsive noise. It employs nets with air filled elastic balloons and special polyethylene-foam elements with high dissipative effects to reduce noise (Elmer and Savery, 2014). The HSD is a lightweight, cost effective (as there are no compressors required), reusable system which requires customisation for each project.

Noise reduction by HSD is largely independent of water depth and currents (up to the tested conditions of 45 m and 0.75 m/s) (BSH, n.d.a). However, for deeper water (>40 m), and presumably quicker current speeds, the practicability and efficiency of this system remains to be proven (Koschinski and Lüdemann, 2020; Verfuss *et al*., 2019). Of the three proven and most frequently used NAS (i.e. HSD, BBC and IQIP-NMS (see section 2), the HSD has the smallest evidence base and has not been used on jacket foundations (Verfuss *et al*., 2019). Nonetheless, the existing evidence does indicate that at least a 10 dB reduction could be expected (Koschinski and Lüdemann, 2020). Traditionally this technology has been implemented alongside a BBC (CEFAS, 2025), as it is designed for maximum efficiency at low frequency, but new designs have a much wider frequency performance and may be effective for higher frequencies in the absence of a bubble curtain (Offnoise-Solutions, pers. comm).

2.2.2 IQIP (formerly IHC) Noise Mitigation Screen (also referred to as Integrated Monopile Installer)

The IQIP Noise Mitigation Screen (IQIP-NMS) is a comprehensive installation system that includes an isolation casing system and provides several additional built-in features which aid in decoupling radiated noise from the water column close to pile during installation. The IQIP system comprises a double-walled steel pipe with an air gap in between, with an additional bubble curtain used in the centre around the pile (Weilgart *et al*., 2023). The IQIP-NMS is the most used type of isolation casing system in offshore wind and has been assessed as the most effective near-pile mitigation system (Weilgart, 2023).

By combining several principles of noise reduction in various layers around the pile, isolation casings, such as the IQIP-NMS, are capable of a high noise reduction comparable to or exceeding that of a bubble curtain (Koschinski and Lüdemann, 2020). Whilst there is less evidence for isolation casings than BBCs, data collected indicates that a noise reduction of at least 10 dB is achievable (Koschinski and Lüdemann, 2020). Current isolation casings are designed and used during installation of monopiles and not jacket piles (IQIP, 2023; Le Monde International, 2023).

The IQIP-NMS technology features a pipe-in-pipe system that reduces SEL up to 17 dB (BSH, n.d.b). It can also be used in conjunction with other systems, for example the use of an IQIP-NMS with a DBBC can reduce SELs up to 22 dB in shallow water depths (ca. 40 m; Weilgart, 2023). The IQIP-NMS performance is independent of current and can be used in any water depth in principle (BSH, n.d.b); however, to date, this system has only been used in water depths of up to 40 m (Weilgart, 2023) and current speeds up to 0.75 m/s (Bellman *et al*., 2020). Verfuss *et al*. (2019) highlight that a new model of NMS would be needed for use in deeper waters (>50 m).

2.2.3 AdBm Noise Mitigation System

The AdBm NMS is a customisable on-pile resonator developed by the company AdBm and was first deployed commercially in 2019 (Verfuss *et al*. 2019). The AdBm is a skirt, fully surrounding the pile, with upturned cups or cavities that are filled with trapped air by hoses. Custom designs can use wider or additional modules to increase attenuation.

Limited studies have focussed on the system's acoustic performance (Weilgart, 2023), but noise reports for Borsselle 2 OWF, which used the AdBm NMS and a DBBC in 32 m water depth in the Dutch North Sea, measured a maximum SEL of 157 dB at a distance of 752 m from the pile (Van Oord, 2020). Degraer *et al*. (2019) report on the AdBm system alone reducing zero to peak SPL by 3–6 dB re 1 µPa at a distance of 750 m from five pile driving events (7.2-7.8 m diameter piles driven using a 3,500 kJ hydraulic hammer in 26–47 m water depth). On their website, AdBm suggest that their system should be used with a DBBC to increase the NMS's performance and compliance with international noise limits, as hammer energies and pile sizes continue to increase (AdBm technologies, 2020); Degraer *et al* (2019) report a 10-11 dB attenuation from a combined AdBm and BBC system.

Measurements undertaken by Jasco Applied Sciences at Ørsted's South Fork Wind on the US east coast showed that the combination of an AdBm and DBBC significantly outperformed the noise attenuation target, suggesting a reduction in excess of 15 dB from the unabated prognosis (Simurda *et al*., 2024).

2.3 Dewatered Cofferdams

Dewatered cofferdams involve a steel tube that surrounds a pile from the seabed to the water surface which creates an air gap between the pile and the water (Bellmann, 2014; Koschinski and Lüdemann, 2020). This gap effectively reduces the sound energy transfer into the marine environment when the cofferdam is sealed at the bottom and dewatered by pumps (Thomsen, 2012 as cited in Koschinski and Lüdemann, 2020).

Cofferdams are not a typical NAS in OWF construction, however they have been used for jacket installations of offshore platforms within depths of up to 40 m (e.g. converter platforms and cable access tower and piles; Wijk, 2013 as cited in Koschinski and Lüdemann, 2020). Full scale prototype monopiles (pile diameter of 5.9 m) have also been trialled using this approach at Anholt OWF on the east coast of Denmark (McKenzie Maxon, 2012; Thomsen, 2012 (both cited in Koschinski and Lüdemann, 2020)), but installation was not successful using this method due to seal failure with the seabed. Although existing evidence indicates a high noise reduction potential of cofferdams (up to 23 dB SEL), the measurements at Anholt only showed a reduction up to 13 dB SEL (McKenzie Maxon, 2012 (as cited in Koschinski and Lüdemann, 2020)).

2.4 Alternative Hammers

Alternative hammer technologies aim to reduce underwater noise at the source by modifying the pile-driving process itself. These methods are particularly relevant for large-diameter monopiles and are being explored as lower-noise alternatives or complements to traditional impact hammers.

2.4.1 Vibro-hammer

Vibratory hammers (or vibro-hammers) are an alternative to the use of impact hammers, and can sometimes be used in combination with them. Unlike impact hammers, the noise generated by this activity is non-impulsive and peaks at low frequencies (<40 Hz; Koschinski and Lüdemann, 2020).

The OWF Nordsee Ost (located in the German sector of the North Sea) used a combination of vibro-pilling and impact pile driving to install 196 pin piles of the 48 jacket foundations for wind turbines and one substation in water depths up to 25 m (Offshore Energy, 2014). A vibro-hammer was also used alongside

impact piling of a monopile in 2017 (van Dorp *et al*., 2022), and for the complete installation of a monopile at Kaskasi OWF in German waters (Fetrati *et al*., 2025). More recently, the Ecowende project has committed to using two types of vibro-technology to installation large monopiles in the North Sea (Ocean Energy Resources, 2025). Pin piles were vibro-piled to 1/3 of the final penetration depth before using an impact pile driving method to final depth (Koschinski and Lüdemann, 2020).

Noise emissions from vibro-piling are in the order of 10–20 dB lower than mitigated impacts of pile driving at identical situations (Gerke and Bellmann, 2012; Kringelum, 2013; as cited in Koschinski and Lüdemann, 2020). However, vibro-piling emits a continuous noise compared to the impulsive characteristic of impact pile driving, which makes direct comparisons difficult (Koschinski and Lüdemann, 2020).

Vibratory hammers are most effective in granular substrates such as sands and gravels. They are less effective in cohesive soils or clays due to higher dampening and resistance (Cape Holland, 2022). Within the Array Area of the Proposed Development the substratum ranges from sandy shell to gravel to the west, north and south of the bank to coarse shell and gravel and some rock to the east of the bank. The bank itself consists of mainly sand, cobbles with shells and pebbles at the northern end of the bank and fine sand at the southern end. The ground conditions at the Proposed Development site pose limitations on the use of vibro-piling, in that this method cannot install piles to required depth.

2.4.2 Pile cushioning

Pile cushioning is a method used to dampen high-frequency impact force and reduce the peak sound pressure (Deng *et al*., 2016). This is achieved by adding a layer(s) of cushioning material between the hammer and pile (Koschinski and Lüdemann, 2020). The cushioning prolongs the duration of each hammer strike pulse, therefore reducing the intensity of the acoustic pulse, but effectively also reduces the maximum energy passing through the hammer.

There are a number of companies developing pile cushioning systems to limit the impact of noise and reduce the material fatigue of the pile as a consequence of pile driving. Examples include MENCK Noise Reduction Unit (MNRU) and Piling Under Limited Stress Equivalent (PULSE; developed by IQIP). Pile cushioning has been shown to reduce noise emissions by 3–6 dB SEL and 9-12 dB SPL at the source (Merchant and Robinson, 2020).

The MNRU is currently being used by East Anglia 3 (EA3) monopile installation. While MENCK advertises a potential noise reduction of 6–12 dB, this figure is based solely on modelling and has not yet been validated through field measurements. However, a conservative 4.5 dB reduction has been assumed in more recent assessments (Scottish Power Renewables, 2025). At the time of writing, the effectiveness of this system in reducing noise during piling at EA3 from field monitoring results has not been published.

Similarly to the MNRU, IQIP advertises PULSE as providing a potential noise reduction of 6–12 dB (6-10 dB SEL and 5-12 dB SPL; IQIP, 2026). PULSE was deployed during the installation of monopiles at He Dreiht OWF in the German North Sea, and when used in combination with a DBBC achieved a noise reduction of up to 24 dB (EnBW, 2024).

2.4.3 EQ (formerly BLUE) Hammer

The EQ Hammer is a new technology developed by Fistuca BV and currently being developed by IQIP. It is a water-based impact system that replaces the typical steel ram weight of an impact hammer. It leads to a longer blow pulse, which reduces noise emissions by up to 20 dB SEL and noise fatigue damage by up to 90% (Weilgart, 2023; Offshore Energy, 2018). There is limited information on the EQ Hammer as it is still in the development phase. The Carbon Trust and Fistuca, in conjunction with industry partners (E.ON, EDPR, EnBW, Equinor, Ørsted, Shell, Sif, SSE, Van Oord, and Vattenfall), completed offshore tests in 2018 using Fistuca BLUE 25M hammer (Offshore Energy, 2018).

At the time of writing (February 2026) , the IQIP website suggests that the EQ hammer can lead to reductions in SELss of between 15 dB and 25 dB. Furthermore the technology will be tested offshore in the coming months, where it will installation an 8m monopile which is smaller than the Proposed Development's upper bound diameter.

3 Literature Review of Avoidance and Deterrent-Based Mitigation Measures

There are a range of avoidance and deterrent-based mitigation measures which are commonly used during pile driving at offshore windfarms to reduce the risk of noise impacts to marine mammals. These measures minimise the likelihood of marine mammals being within the area of impact, by ensuring that operations do not commence when marine mammals are detected, and by employing deterrent techniques to encourage individuals to move away from the area prior to start-up. Avoidance and deterrent-based mitigation measures are already used in Irish waters, therefore this section provides a review of the approaches in Irish waters, using the DAHG (2014) guidance.

3.1 Marine Mammal Mitigation Zone (MMMZ) Monitoring

The marine mammal mitigation zone (MMMZ) is a pre-defined area which is monitored prior to the start of noisy activities such as piling. The approach to defining the size of the MMMZ varies depending on the jurisdiction and the activity being undertaken. DAHG (2014) guidance recommends a MMMZ of 1,000 m for piling. It is also beneficial to consider the outputs of activity-specific noise modelling when considering an appropriate MMMZ size, as this can used to determine the extent of noise propagation to pre-defined thresholds (such as thresholds for the onset of PTS or TTS; Southall *et al.*, 2019). There is no guidance in Ireland as to which threshold should be compared to the recommend MMMZ sizes. In the case of the Proposed Development, the largest impact range for instantaneous PTS-onset predicted for the Proposed Development (i.e. 680 m). Therefore, implementation of a 1,000 m MMMZ for piling will also minimise the risk of marine mammals being within the instantaneous PTS-onset range, as well as part of the cumulative PTS-onset range and TTS-onset ranges.

Monitoring of the MMMZ can be undertaken through a range of methods. The primary method is visual monitoring by Marine Mammal Observers (MMOs), however other methods such as passive acoustic monitoring (PAM) are also mentioned in the DAHG (2014) guidance. Monitoring will be undertaken during the defined pre-activity search period, which for piling in waters up to 200 m deep, should be at least 30 minutes (DAHG, 2014). Monitoring should also be taken during the initial piling sequence (i.e. ramp-up and soft start).

3.1.1 Marine Mammal Observers (MMOs)

DAHG (2014) requires a minimum 30-minute pre-piling search, carried out by a trained MMO positioned to provide full 360° visual coverage of the MMMZ. The purpose of this search is to maximise the likelihood of detecting marine mammals within the MMMZ prior to the start of piling. If a marine mammal is detected within the MMMZ during the pre-piling search, the piling procedure will be delayed until it has been confirmed that the individual(s) has vacated the MMMZ, and there have been no detections for at least 20 minutes. This ensures, as far as possible, that marine mammals are outside of the MMMZ and so zone of greatest impact prior to the start of piling.

Limitations of MMOs as mitigation in isolation, include the possibility of missing marine mammals in the MMMZ. This may be because they are underwater. There is also a reduced chance of detecting low profile marine mammals, such as harbour porpoise, particularly in a Beaufort sea state greater than two (Gunnlaugsson *et al.,* 1988, as referenced in Teilmann, 2003), which correlates to a probable wave height of greater than 0.6 m (Met Office, 2026). In contrast, larger cetaceans (i.e. dolphins and whales) can generally be sighted under a sea state four (Smith *et al.,* 2020). In practice, DAHG (2014) advise that visual monitoring for marine mammals may be conducted at Sea State 4 or less, corresponding to a wave height between 1.25 m and 2.5 m. However, the Applicant highlights that it is very unlikely that monopile installation would occur above a wave height of 2 m due to environmental limits associated with monopile

installation. MMOs can also be limited in their ability to monitor the full MMMZ if their location on the vessel does not have full unobstructed view of the MMMZ or they are not sufficiently high above the sea surface. They are also unable to conduct monitoring during the hours of darkness, and may not be able to view the full MMMZ during periods of poor visibility (e.g. fog).

3.1.2 Passive Acoustic Monitoring (PAM)

Passive Acoustic Monitoring (PAM) provides an effective complement to MMO visual monitoring in periods of poor visibility. It is also the only method regularly used at night (JNCC, 2023). The purpose of PAM is the same as for visual monitoring, in that it is used to monitor the MMMZ and reduce the risk of marine mammals being within the MMMZ prior to commencement of piling. It has been routinely used as mitigation in jurisdictions using the JNCC Guidelines (principally the UK, although also adopted in other countries where there are no country-specific guidelines), and has been used since 2002 (JNCC, 2023).

PAM uses a hydrophone array, deck cable, data acquisition units, and computer/laptop set up with acoustic analysis software to provide real-time detection of marine mammal vocalisations (JNCC, 2023).

Limitations of PAM include that it may miss animals that are not vocalising, such as individuals of species which vocalise less frequently (such as seals; JNCC, 2023). Some species do vocalise more frequently and are regularly detected in PAM arrays, such as harbour porpoise and bottlenose dolphin. One supplier reported that harbour porpoise can be detected up to a maximum of 300 m from their PAM system, and at much greater distances for dolphins (specifically C-PODs (Ocean Science Consulting, 2025). To circumvent range limitation with individual devices a PAM array can be deployed to ensure coverage is attained for the full range required from the piling location.

In summary, there are advantages and limitations to undertaking monitoring of the MMMZ using either visual or acoustic methods (i.e. avoidance methods). Therefore, it is beneficial to also consider deterrent-based mitigation measures such as acoustic deterrent devices (ADDs), which can be complementary to avoidance methods and further contribute to reduced risk of marine mammals being within noise impact ranges.

3.2 Acoustic Deterrent Device (ADD) Activation

ADDs are routinely used prior to piling in OWF, with a large body of evidence available to demonstrate their effectiveness in deterring marine mammals away from mitigation zones (McGarry *et al.*, 2022; Phillips *et al.*, 2025). A review of ADDs, including the ranges over which they effectively deter different marine mammal species, is provided in the ADD Review (Volume III, Appendix 25.2: Marine Mammal Mitigation Plan, Annex A).

ADDs can be used to mitigate larger impact ranges than those that can be monitored through visual or acoustic methods (nominally a maximum of 1 km). For example, the Proposed Development predicts that cumulative PTS-onset ranges will be in the region of kilometres, and so greater than the area that can be effectively monitored. While monitoring the MMMZ is sufficient to avoid instantaneous PTS, cumulative PTS-onset ranges extend beyond 1,000 m for LF and VHF cetaceans, creating a residual risk that cannot be addressed through visual/PAM monitoring alone. In this case, the ADD provides an essential deterrent-based mitigation measure to encourage animals to move beyond these larger cumulative impact ranges.

The approach to determining appropriate ADD duration varies between jurisdictions and activities, and can also take into account activity-specific noise modelling. In the published studies of ADD efficacy at deterring marine mammal species, durations can vary from shorter durations (e.g. 15 minutes; McGarry *et al.*, 2017) to over an hour. Marine licences for noisy activities in the UK specify durations of between 15-80 minutes (Majewska *et al.*, 2025), highlighting that there is no single prescribed duration and that UK regulatory advice considers activity-specific factors. In Scottish waters, it is recommended that ADDs are

on for 15 minutes before the start of piling to deter harbour porpoises from immediate injury zones (i.e. the instantaneous PTS-onset zone) (Benhemma-Le Gall *et al.*, 2024). In contrast, in English waters the industry-standard approach to determine appropriate ADD duration is to calculate it using modelled PTS-onset ranges and estimated flee times, based on conservative swim-speed assumptions for relevant species. Industry-standard flee speeds in English waters are an average swim speed of 1.5 ms^{-1} for harbour porpoise, dolphins and seals (Otani *et al.*, 2000), and 3.25 ms^{-1} for minke whale (Blix and Folkow, 1995), which have been used by the Proposed Development. To note, evidence shows marine mammals can swim considerably faster when disturbed (Kastelein *et al.*, 2018). The Proposed Development has considered both approaches in determining the ADD duration. Using the English approach, an ADD would need to be on for at least 8 minutes to displace animals fully beyond the PTS-onset range, or 12 minutes to displace animals fully beyond the 1,000 m r_{safe} distance. Therefore, a 15 minute ADD duration has been taken forward, to ensure precaution and reflect operational considerations in the field, and to align with the industry-standard ADD duration in Scotland. Therefore, this approach is precautionary and provides a robust basis for determining ADD activation periods. To highlight, by using this approach the Proposed Development will activate the ADD for sufficient duration to deter all marine mammal species beyond the distance at which instantaneous and cumulative PTS-onset may occur.

3.3 Ramp up

The commencement of piling will predominantly begin at lower hammer energies due to engineering considerations, however this low-energy start also can also have benefits for marine mammals in that they are exposed to comparatively low-level sound that can encourage them to flee the area before hammer energies increase and have greater potential to cause auditory impacts. The incremental increase in energy at the start of piling is referred to as a “ramp-up”.

DAHG (2014) states that an appropriate ramp-up procedure must be used when commencing pile driving where the output peak sound pressure level (in water) from any source including equipment testing exceeds 170 dB re: 1µPa @1m. This ramp up must consist of a controlled build-up of acoustic energy output, occurring in consistent stages to ensure a steady and gradual increase over the ramp-up period, which should be 20 – 40 minutes. Similar ramp-up or “soft-start” procedures are including in guidance for other jurisdictions such as the UK (JNCC, 2010). Initiating piling at a lower energy allows for any marine mammals to move away from the noise source, reducing the likelihood of auditory impacts.

Following the completion of the ramp-up, piling can occur at full energy. In practice, ramping up of energy during piling for offshore wind typically extends beyond the defined ramp-up time, in that full energy is typically reached notably later than 20-40 minutes, and often the maximum hammer energy is not required.

The available guidance on the ramp-up procedure from DAHG (2014) is high-level and not prescriptive. As a result, the piling profile during the ramp-up period can vary between projects, whilst remaining within the bounds of the guidance. Parameters such as starting hammer energy, the nature of the incremental stages in terms of duration, percentage hammer increase, and the strike rate, can all be varied in the process of defining the ramp-up. The ramp-up profile must be achievable and feasible from an engineering perspective, however it can also be amended to achieve further reductions in the auditory impact ranges to marine mammals (Matei *et al.*, 2024).

4 Project Specific Analysis of Mitigations

4.1 Practicality of using NAS within the ABWP2 Offshore Site

4.1.1 Bubble Curtains

With regards to practicality of utilising this technology for the Proposed Development, the following needs to be considered:

- Transport and Installation (T&I) considerations:
  - Bubble curtains will require another offshore construction vessel to come to the monopile installation location prior to the monopile installation vessel commencing monopile piling operations – this will mean added time to the overall operations.
  - The time taken to install and set up the bubble curtains will depend on the site conditions, on a typical site the installation and set-up of the bubble curtain system takes approximately 3-5 hours.
  - Given the strong current conditions in the field and the short windows available for monopile installation (jack up of vessel, installation operations), adding an extra 3-5 hours (potentially longer) on top of monopile installation operations can make it even more difficult to find an acceptable window for commencing installation operations. It is desired that jack up the installation vessel and commence monopile installation operations as soon as possible as the weather windows are narrow, therefore utilising bubble curtains for the Proposed Development site would not be practical.
  - Proximity of the monopile locations to shallow water may make navigation hazardous for the bubble curtain installation vessel as they would have to lay the curtain's hoses between the sandbank and the monopile.
- Operating of bubble curtains in the Array Area:
  - Given the system requires currents to be less than 0.75 m/s to be fully effective, and the maximum currents in the Array Area can reach up to 2.7 m/s, effectiveness of the system would be extremely constrained. Given currents would only be below 0.75 m/s for limited durations on each tidal cycle, pile driving at each location would extend to multiple tidal cycles. The limited sound reduction effects of the bubbles due to currents, along with the current related temporal extension of pile driving, may have a net detrimental effect in terms of impacts on marine mammals at the Proposed Development.
  - The ability of the bubble current hoses to remain in position on the seabed at times of high current still needs to be validated. It is not clear if standard commercially available bubble curtain solutions would be suitable for the site.
  - Furthermore, it is necessary for remotely operated vehicle (ROV) on board the BBC installation vessel to confirm that the BBC hoses are laid and function correctly. Given currents at site, and ROV sensitivity to currents, this step could only be performed at slack water, further delaying cycle times and temporal impacts from piling.

4.1.2 Hydro sound Dampers (HSD Technology – Near Pile System)

This HSD system net can be pre-installed onto/underneath the monopile gripper (the gripper is used to stabilise the monopile during piling operations) and therefore will only require lowering down to the seabed once the monopile is engaged within the gripper. From a general T&I perspective, this is a good solution. It has the following advantages:

- Easy to install – In general, the monopile installation process would be barely affected by this method as it has a quick installation time (lower the net/basket down to the seabed). No additional space will be required on the monopile installation vessel deck, which is beneficial to the Proposed Development as it can make use of the full deck space for the monopiles.

Potential limitations with the system include:

- It is not universally available on all installation vessels. Therefore, if required, it may limit the optionality the Proposed Development has in the supply chain.

- It would need to be validated that standard versions of the system could be deployed and operated without current related restrictions in the Array Area. If current related issues restricted the times in the tidal cycle piling could occur, this could lead to an extension of the overall pile driving campaign which could negate the mitigative effects of this technology. Installation Contractor feedback is “this system has additional environmental limits, particularly with respect to currents, whereas the monopile installation itself is not significantly limited by currents. This can result in the resonator net deforming and flexing in the water, likely reducing its efficacy”.

4.1.3 AdBm Noise Mitigation System – Near Pile Mitigation

Similar to the HSD Technology, the AdBm skirt can be installed onto/underneath the monopile gripper making for easy setup of the system (Figure 5.4).

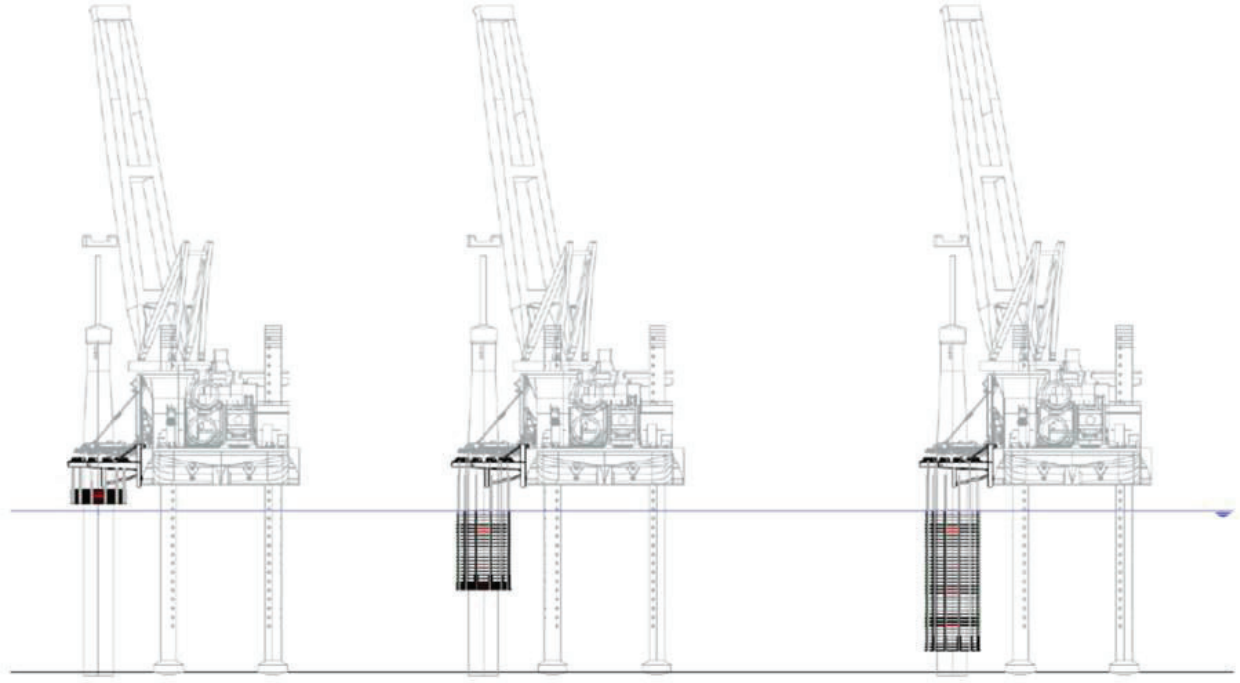


Figure 5.4 Illustration of the AdBm system setup

From a T&I perspective, this is a generally good solution. It has the following advantages:

- Easy to install – as mentioned, the skirt will be pre-installed underneath the monopile gripper. The monopile installation process would be barely affected by this method as it has a quick installation time (simply lower the skirt down to the seabed).
- No additional space will be required on the monopile installation vessel deck, which is beneficial to the Proposed Development as it can make use of the full deck space for the monopiles.
- Understanding is the skirt is a rigid system and can work in strong currents.

Potential limitations with the system include:

- It is not universally available on all installation vessels. Therefore, if required it may limit the optionality the Proposed Development has in the supply chain.
- It would need to be validated that standard versions of the system could be deployed and operated without current related restrictions in the Array Area. If current related issues restricted the times in the tidal cycle piling could occur this could lead to an extension of the overall pile driving campaign which could negate the mitigative effects of this technology.

4.1.4 Hammer Add-ons (IQIP PULSE and MENCK Noise Reduction Unit, MNRU)

From a T&I perspective, the add on to the hammer is a good solution as the damper is already on the hammer, meaning no need for additional setup at each location prior to monopile installation operations once the PULSE is initially fitted and hence timings will not be impacted.

Given the PULSE increases the overall length of the piling hammer, it adds to the required hook height the installation vessel's crane needs to achieve, therefore its use may preclude the use of some installation vessels whose crane hook height is marginal for monopile installation at the Proposed Development.

4.1.5 IQIP Noise Mitigation System (NMS)

The NMS is not available for rental and needs to be built project specific.

It has the following advantages:

- Reduces noise at the source.
- Less sensitive to wide-area currents than a bubble curtain.

Potential limitations with the system include:

- Currently not available for rental and has to be built for project.
- Likely to require extensive design interface with installation vessel and its monopile gripper, unlikely to be technically feasible for all installation vessels and likely to be commercially prohibitive for a single 800 MW project such as the Proposed Development.
- It is unknown if it could be feasibly designed to withstand strong currents at the Proposed Development.

4.2 Summary of Mitigation Status and Assessment of Suitability for the Proposed Development

Table 5.4 provides a summary of various avoidance, deterrent and NAS technologies, their compatibility to different operational contexts, their typical effectiveness and their suitability for the Proposed Development. This table also distinguishes between primary and secondary noise mitigation measures.

Table 5.4 Summary of potential mitigations and performance parameters. Where depth is included with a noise reduction value, this is the water depth the device was tested within. A key is presented in the final row.

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
Bubble Curtains	Big bubble curtains	Secondary	Noise Reduction via reflection, scattering and absorption (frequency-dependent)	Single, double, triple application; isolation casing; Hydrosound Dampers; AdBm; Alternative hammers	Noise Reduction: Single: 11–15 dB SEL (depth: 25 m) Double: 12–18 dB SEL (depth: 40 m)	Proven effectiveness and efficacy via extensive application at multiple OWFs	Strong tidal currents at the Proposed Development site (reaching peak velocities of 2.75 m/s) which would pose restrictions for this NAS. Optimal current speeds for the use of BBC are <0.75 m/s.
	Little bubble curtains	Secondary	Noise Reduction via reflection, scattering and absorption (frequency-dependent)	Single application; isolation casing; Hydrosound Dampers; Alternative hammers (in theory)	Noise Reduction: 11–13 dB SEL	Experimented in the German test field, but not further developed for commercial use.	Only suitable for shallow water depths and low current speeds (at time of testing; nothing relevant since). Not developed for commercial use
Near-pile systems	Hydrosound Dampers	Secondary	Noise Reduction via encapsulated resonator	Bubble curtains; Alternative hammers	Noise Reduction: Up to 12 dB SEL (depth: 40–60 m)	Proven effectiveness (in principle unlimited by	In principle, no environmental limitations, though deployment may

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
			system. Scattering and Noise Reduction via absorption by resonators, reflection, dissipation and material damping (frequency tuning possible)			water depth, ~8–13 m pile diameter)	prove difficult given high currents at site. Could limit supply chain as may not be an option with all installation vessels.
	IQIP Noise Mitigation Screen	Secondary	Noise Reduction via shielding, reflection	Bubble curtain; Alternative hammers (in theory)	Noise Reduction: 10–17 dB SEL (depth: <45 m)	Proven effectiveness	Not available for rental and would need to be built specifically for the Proposed Development. Potential technical issues integrating with installation vessel and designing for strong currents at site.

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
	AdBm NMS	Secondary	Noise Reduction via encapsulated resonator system. Broadband frequency attenuation	Bubble Curtains; Alternative hammers (in theory)	Noise Reduction: Up to 3–6 dB SPL at targeted frequency (depth: < 47 m)	Full scale model successfully tested by Van Oord in 2019. Since used offshore in conjunction with other NAS (in principle not constrained by water depth).	In principle, no environmental limitations though no validated for high current environment such as at the Proposed Development. Could limit supply chain as may not be an option with all installation vessels.
Dewatered Cofferdams	Dewatered Cofferdams	Secondary	Noise Reduction via decoupling noise from the water column	Bubble curtain; Hydrosound Dampers; Alternative hammers (in theory)	Noise Reduction: 13 – 23 dB SEL (depth: <20 m)	Monopile (5.9 m pile diameter) full scale prototype tested offshore in 2011 and 2012, but not used on OWF since issues with prototype testing.	Limited evidence base on its use for OWF. Not at all practical for project.
Alternative hammers	Vibratory Hammer	Primary	Noise Reduction via alternative piling method using low	All secondary noise mitigation measures (in theory)	Noise Reduction: 10–20 dB SEL, (depth: <25 m)	Proven technology in combination with impact piling.	Ground conditions at the Proposed Development site pose limitations on the use of vibro-

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
			frequency oscillations			Exclusive vibropiling: Offshore pilot wind turbine with monopile successfully installed in Dutch waters.	hammers, in that this method cannot install piles to required depth.
	Pile cushions, e.g. IQIP PULSE, MENCK MNRU	Primary	Noise Reduction via dampening high-frequency noise and wave amplitudes, prolongation of the pulse duration	All secondary noise mitigation measures (in theory)	Noise Reduction: 3–6 dB SEL 9–12 dB SPL	Proven modular add-on that can be used with hydrohammers. PULSE and MNRU have been used on projects. Also proven to reduce installation fatigue.	No environmental limitations. Poses some technical considerations for installation operations which may preclude some installation vessels.
	EQ Piling Technology	Primary	Noise Reduction via prolongation of the pulse duration, elimination of metal-on-metal contact	All secondary noise mitigation measures (in theory)	Noise Reduction: 19–24 dB SEL (depth: 22.4 m)	Full scale prototype successfully tested under offshore conditions, improvements on technology currently being	Limited evidence based on its effectiveness. Not currently commercial available.

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
						studied and implemented. Further testing programmed in coming months.	
Avoidance measures	Visual Monitoring	N/A	A minimum of 30-minutes pre-piling search, carried out by an MMO positioned to provide full 360° visual coverage of the MMMZ, ensuring that no marine mammals are within the MMMZ prior to commencement of piling.	All mitigation measures	N/A	Proven mitigation method which is required by DAHG (2014).	No limitations.
	PAM	N/A	Provides real-time detection of marine	All mitigation measures	N/A	Proven mitigation method routinely used under	No limitations.

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
			mammal vocalisations, ensuring that no marine mammals are within the MMMZ prior to commencement of piling.			JNCC-based mitigation since 2002 (JNCC, 2023).	
Deterrent-based measures	ADD	N/A	The use of an acoustic deterrent to ensure that no marine mammals are within the MMMZ prior to commencement of piling.	All mitigation measures	N/A	Proven mitigation method routinely used during the development of offshore windfarms (McGarry *et al.*, 2022; Phillips *et al.*, 2025).	No limitations.
Deterrent-based measures	Ramp up	N/A	A controlled build-up of acoustic energy output, occurring in consistent stages to	All mitigation measures	N/A	Proven mitigation method which is required by DAHG (2014).	No limitations.

Type	Method	System type	Mitigation Principle	Can be used in combination with:	Quantitative Effectiveness	Development Status	Suitability for the Proposed Development site
			ensure a steady and gradual increase over the ramp-up period.				

Notes:

- Development Status: **Green:** Commercially available and frequently employed in offshore wind construction; **Orange:** In development, not commercially available/very limited track record; **Red:** Not proven or used only in very limited circumstances.
- Suitability for the Proposed Development, based on non-acoustic, engineering limitations: **Green:** Theoretically suitable; **Orange:** Some limitations; **Red:** Not suitable.
- SEL is measured in dB re 1 μPa^2s and SPL in dB re 1 µPa.

5 Conclusion

There are two approaches to the regulation of underwater noise in the national jurisdictions reviewed. The first is a Source-and-Threshold approach, which is used in Germany and Belgium, and has resulted in strict decibel limits and widespread use of noise reduction measures. The second is the Receiver-and-Exposure approach, which is adopted in Ireland and other regions such as the UK. This approach considers the noise received by receptors and whether it will result in a significant negative effect, at which point further mitigation should be applied until impacts are within acceptable levels. As Ireland adopts this second approach, there are no strict noise limits in place.

International approaches to noise regulation have been reviewed and considered, including Denmark, Belgium, Germany, Netherlands and Poland. Each country has undertaken a tailored approach to setting thresholds, that take into account their specific national and international legislative obligations, the local environment and the marine mammal species most frequently present. To note, all countries reviewed are located in the Southern North Sea and therefore their waters are typically shallow (<40 m), with limited maximum current speeds (0.75 m/s), and several countries have taken an approach that focusses only on the harbour porpoise as it is the most frequent species in the region. Nevertheless, of these, the Danish approach is considered the most appropriate to Irish waters, for the reasons outlined in Section 1.4., under the Danish approach, the developer must consider noise impact reduction methodologies, as has been done by the Proposed Development, and may choose to use NAS or not but must comply with the relevant PTS thresholds.

There are a wide variety of mitigation strategies currently available to reduce the risk of auditory impacts to marine mammals during pile driving. One type is avoidance and deterrent-based measures, such as the use of marine mammal monitoring, ADDs, and ramp-ups, all of which aim to to reduce the risk of mammals being present in the vicinity of the noise source. These measures are commonly used in jurisdictions that adopt a Receiver-and-Exposure approach, such as the UK and Ireland, and have been committed to by the Proposed Development.

Another type of mitigation strategy is NAS technologies, which are designed to reduce generation or propagation of underwater noise into the wider marine environment. Several of these NAS technologies are commercially available and have been deployed on multiple OWFs with field measurements from monitoring demonstrating their efficacy, while others remain in the prototype/testing phase of development. The effectiveness of each system is dependent on a number of factors, including but not limited to, water depth and oceanographic features (e.g. current speed), size (primarily diameter) of the pile and foundation type.

The selection of an appropriate underwater noise mitigation strategy for the Proposed Development site must be appropriate to the impacts and crucially must be cognisant to site-specific factors, including monopiles exceeding 7 m diameter, and the combination of strong tidal currents reaching peak velocities of 2.75 m/s with shallow water depth. Notwithstanding the fact NAS has been demonstrated not to be a necessary mitigation for the Proposed Development, these conditions would limit the effectiveness of certain NAS technologies, particularly those sensitive to current or depth, and must be carefully considered when designing an underwater noise mitigation strategy.

As per the under water noise modelling assessment (Volume III, Appendix 11.1: Underwater Noise Assessment (Revised March 2026)) it has been demonstrated that the piling strategy for the Proposed Development can comply with the Danish thresholds. An r_{safe} of 1000 m will be established within which it will be ensured that no marine mammals are present prior to the commencement of piling through the deployment of ADDs. The clearance of the r_{safe} zone will be validated either by Marine Mammal Observer or PAM, depending on the prevailing conditions at time of piling pre-start.

The commitment to establish a 1000 m r_{safe} is precautionary, given that analysis results indicate an r_{safe} of 870 m is required to comply with the Danish thresholds i.e. that a maximum PTS-range of 870 m is predicted. Furthermore, based on fleeing speeds, the proposed ADD deployment duration of 15 minutes is expected to deter marine mammals to distances notably greater than the PTS-onset range, to 2.9 km for minke whale and 1.4 km for other marine mammal species, thereby also providing partial displacement from the TTS zone prior to the commencement of piling. This approach has been subject to a Risk Assessment in compliance with the 2014 DAHG guidance and it has been concluded that the proposed approach is extremely unlikely to cause injury to marine mammals. Therefore, as the Danish thresholds can be met through the use of a tailored ramp-up scenario and avoidance and deterrent-based mitigation measures, no NAS are required to be implemented by the Proposed Development.

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