TECHNICAL REPORT OF HES OWF 2030

Underwater Noise Hesselø OWF

ENERGINET

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Applicable contract(s) governing the provision of this Report:

Objective:

The objective is to perform an analysis of the propagation of underwater noise from pile-driving based on project assumptions provided by the Client.

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1 LIST OF ABBREVIATIONS

Abbreviation	Definition
DBBC	Double Bubble Curtain
DEA	Danish Energy Authority
HES	Hesselø
HF	High Frequency
HSD	Hydro Sound Damper
LF	Low Frequency
OWF	Offshore Wind Farm
PCW	Phocid Carnivores in Water
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High Frequency

2 EXECUTIVE SUMMARY

In 2018, all parties in the Folketing (Danish parliament) decided to build three new offshore wind farms, including Hesselø Offshore Wind Farm (OWF), which was part of the next steps towards achieving 100% renewable energy in the electricity system in 2020. It was decided in the climate agreement in 2020 that Hesselø OWF should distribute power to the electricity market in 2027. However, the tender process was put on hold in June 2021 after preliminary studies had shown areas of soft seabed in large parts of the area. In the climate agreement from June 2022, it was decided that the area for the Hesselø OWF should be moved to the southwest of the original area. The installed power remains the same, namely 800-1,200 MW, and there have been no changes to the corridor for the export cables to land or to the plan for the associated facilities on land. According to the plan, Hesselø OWF should be in operation in 2029.

The planning area for the Hesselø OWF is located in the Danish part of the Kattegat, approximately 30 km north of Zealand and approximately 25 km east of Djursland. The area has an area of approximately 166 km^2. The offshore wind farm is connected to the electricity grid on land via export cables, which are brought ashore at Gilbjerg Hoved, west of Gilleleje on Zealand's north coast.

A study of underwater noise emitted from the installation of wind turbine foundations has been conducted. The study is based on the guidelines of the Danish Energy Agency (DEA) regarding underwater noise emission from installation of offshore wind farms. The underwater noise emitted from the installation of turbine foundations was modelled using dbSEA modelling software. The cumulative sound exposure noise levels were numerically modelled and calculated for the whole piling sequence for two different hammer types and sequences, and two different pile diameters defined in Section 3. The required noise mitigating and distance-to-threshold (DTT) were calculated for each scenario.

The 13-meter monopile requires noise mitigating measures to adhere to DEA's guidelines due to excesses found for the weighting groups low frequency (LF), Phocid Carnivores in Water (PCW) and very high frequency (VHF). The necessary attenuation of the mitigating measures is up to 16.4 dB. Conversely, the 15-meter monopile needs a reduction of up to 17.4 dB, for the weighting groups low frequency (LF), Phocid Carnivores in Water (PCW) and very high frequency (VHF)

In the absence of mitigating measures, it is assumed that the radius to the pressure thresholds r_{PTS} exceeds the safe radius r_{safe} thus prohibiting piling activities as per DEA's guidelines.

If the distance-to-threshold (DTT) for all scenarios remains under 50 meters, then provided that the safe radius, r_{safe}, exceeds 50 meters, piling can proceed without requiring acoustic deterrent devices. This remains valid when utilizing both a double big bubble curtain (DBBC) and a hydro sound damper (HSD), with their combined effect assumed to be at least 18 dB according to [1].

3 INTRODUCTION

In 2018, all parties in the Folketing (Danish parliament) decided to build three new offshore wind farms, including Hesselø Offshore Wind Farm (OWF), which was part of the next steps towards achieving 100% renewable energy in the electricity system in 2020. It was decided in the climate agreement in 2020 that Hesselø OWF should distribute power to the electricity market in 2027. However, the tender process was put on hold in June 2021 after preliminary studies had shown areas of soft seabed in large parts of the area. In the climate agreement from June 2022, it was decided that the area for the Hesselø OWF should be moved to the southwest of the original area. The installed power remains the same, namely 800-1,200 MW, and there have been no changes to the corridor for the export cables to land or to the plan for the associated facilities on land. According to the plan, Hesselø OWF should be in operation in 2029.

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DNV's Section for noise and vibration, commissioned by Energinet, has carried out an analysis of underwater noise generated by installation of wind turbine foundations off the Danish coast. Several areas are under investigations as part of the project "Mere Havvind 2030". The windfarm layout of Hesselø is presented in Figure 3-1 and the coordinates are presented in Appendix A, the scenario presented in the figure is Scenario 2 with 20 MW turbines.

The report will follow DEA's guidelines for underwater noise, and its requirement to include two cases. The first case is the reference case where a installation without use of noise mitigation is presented in Chapter 9. The second case is the planned construction case presented in Chapter 10. These scenarios will be described more thoroughly in their respective chapter. Detailed information about the reference case and the planned construction case, can be found in DEA's guidelines.
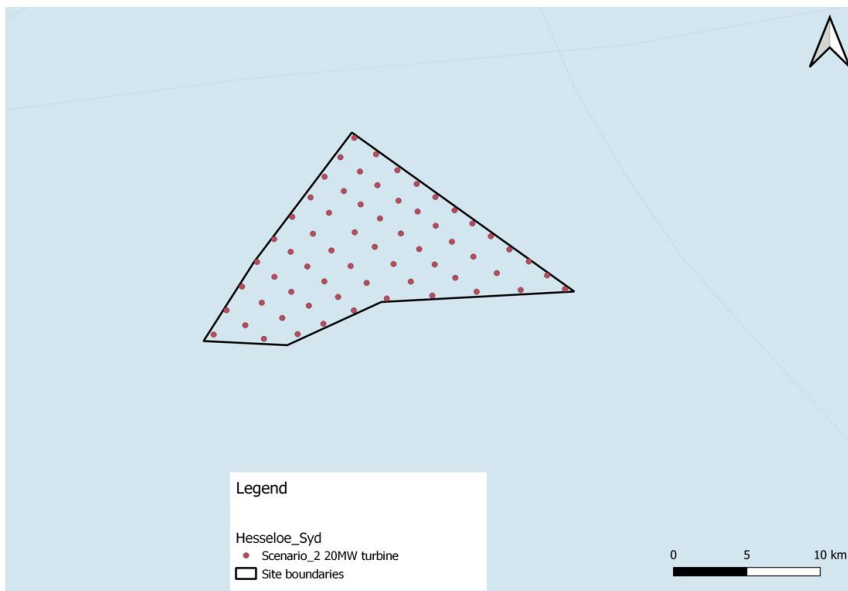
Figure 3-1 OWF Layout

4   MAIN PARTICULARS OF OWF

For the Hesselø (HES) OWF the type of foundations, size of turbines and final layout has not been decided. For the purpose of this underwater noise study two scenarios have been established. The Main Particulars and piling sequence detailed below are provided solely as example parameters and are not indicative of those that will be implemented. These parameters are intended to illustrate hypothetical scenarios.

Table 4-1 Main Particulars of OWF

General	
Area	166 km^2
Name of OWF	Hesselø
Nameplate Capacity	15 MW 20 MW
Underwater noise regulation	DEA Guideline for Underwater Noise [2]
Foundation	
Type	Monopiles
Diameter (15 MW)	13 m
Diameter (20 MW)	15 m
Hammer Type 1	
Manufacturer	IHC
Type	S – 4000
Power	4000 kJ
Hammer Type 2	
Manufacturer	Unknown
Type	Unknown
Power	6000 kJ

The hammer sequences are given in

Table 4-2 and Table 4-3 for the 4000 kJ and 6000 kJ hammer respectively.

Table 4-2 – Piling sequence for the 4000 kJ hammer.

Hammer strike energy [kJ]	Number of Blows	Frequency [Blows/min]
400	225	15
1000	75	15
2000	75	15
3000	75	15
4000	10050	30

Table 4-3 – Piling sequence for the 6000 kJ hammer.

Hammer strike energy [kJ]	Number of Blows	Frequency [Blows/min]
400	225	15
1000	75	15
2000	75	15
3000	75	15
4000	75	15
5000	75	15
6000	6400	30

5 THEORETICAL BACKGROUND

5.1 Sound Exposure Level (SEL)

The sound exposure level SEL is defined as ten times the logarithm to the base 10 of the ratio of the time-integrated sound exposure level E_p to a reference value in ISO 18405:2017 [2]. The convention for underwater noise is to use a reference value of $E_{p,0} = 1\ \mu\text{Pa}^2\ \text{s}$, which was used in this report.

$$L_{E,p} = 10 \log_{10} \frac{E_p}{E_{p,0}}\ \text{dB}$$

where

$L_{E,p}$ = Sound exposure level (SEL),

E_p = Time integrated sound exposure level,

$E_{p,0}$ = Reference sound exposure level.

The cumulative sound exposure level (SEL_{cum}) used in this report is defined as

$$L_{E,cum} = 10 \log_{10} \frac{E_{cum}}{E_0}\ \text{dB}$$

The values that will be calculated in this report will be the cumulative sound exposure level for the whole hammer sequence. Only one piling sequence is assumed during a 24-hour period. Note that multiple piling operations each day, is not covered in this report.

$$L_{E,cum,24h,xx} = 10 \log_{10} \sum 10^{\frac{L_{E,p}}{10}}$$

5.2 Root-mean-square sound pressure level (SPL)

The rms SPL is defined as the mean of the squared pressure given as

$$p_{rms} = \frac{1}{\Delta t} \int_{t_1}^{t_2} p^2(t)\ dt$$

where

p_{rms} = Mean Squared Pressure,

$\Delta t = t_2 - t_1$ = Time interval.

The associated dB – value is defined as

$$L_{p,rms} = 20 \log_{10} \left(\frac{p_{\text{rms}}}{p_0} \right)\ \text{dB}$$

where

$L_{p,rms}$ = Sound Pressure Level (SPL),

p_0 = Reference value. Conventionally 1 µPa for underwater sound.

The threshold for behavioral reactions is determined by the Sound Pressure Level (SPL) within a time interval that corresponds to the average integration time of the mammalian ear, estimated to be 125 milliseconds and further denoted as $L_{p,,rms,125ms}$.

$$L_{p,,rms,125ms} = L_{E,p} + 10 \log_{10}(0.125) = L_{E,p} + 9\ \text{dB}$$

6   REFERENCE SOURCE LEVELS

The source levels were scaled by third octave band frequency SEL levels based on piling of monopile wind turbine generator (WTG), measured at a distance of 750 m as reported in [3]. The scaling is based on hammer strike energy and pile diameter, using the following equation, taken from [3]

$$L_{E,p} = L_{E,p,0} + k_E \log_{10}\left(\frac{E_i}{E_0}\right) + k_d \log_{10}\left(\frac{d_i}{d_0}\right)$$

where

$L_{E,p,0}$ = Unscaled sound exposure level,

k_E = Hammer strength energy scaling coefficient,

k_d = Pile diameter scaling coefficient,

E_i = Hammer Energy,

E_0 = Hammer Energy Reference,

d_i = Pile diameter,

d_0 = Reference Pile Diameter.

The scaling coefficient follows [3] as $k_E = 10$ and $k_D = 16.7$. The reference sound exposure level per third octave band is taken from [4] and shown in Figure 6-1 – SEL 1/3 – Octave band reference values. The blue line is the idealized values which was used. The SEL levels can be linearly scaled for diameter and power.
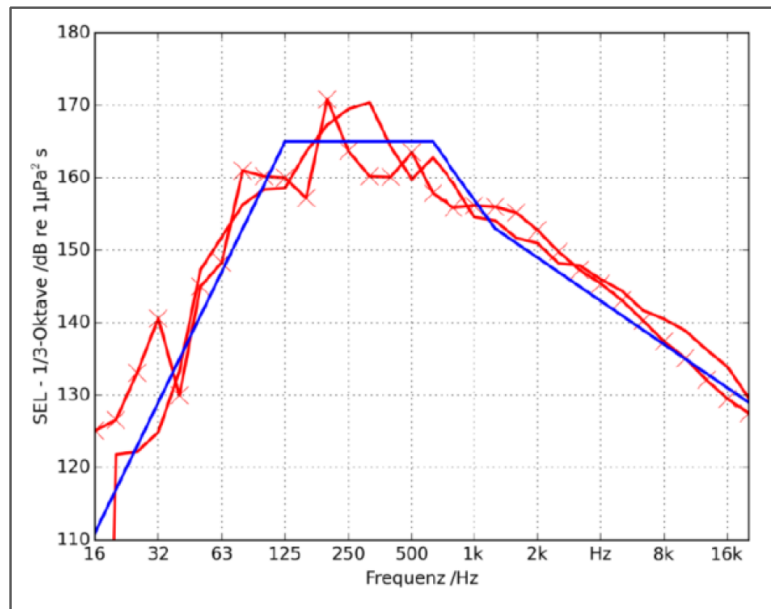
Figure 6-1 – SEL 1/3 – Octave band reference values [4]

The depicted octave band reference values further are backtracked to 1 m using [5], assuming a 4.5 dB increase for each halving of distance. The estimated propagation loss for sound travelling over a distance of 750 meter to 1 meter is calculated to be 43.1 dB, which was added to the scaled SEL values on which the source levels are based. The sound exposure levels outside the frequency band 16 – 20k Hz is unknown. However, the highest values are between 125 Hz and 750 Hz, with decaying values for both sides of this band indicate negligible amplitudes for frequencies outside the 16 – 20k Hz band. The resulting source levels backtracked from 750 m given in SEL's single strike are shown in Figure 5.2
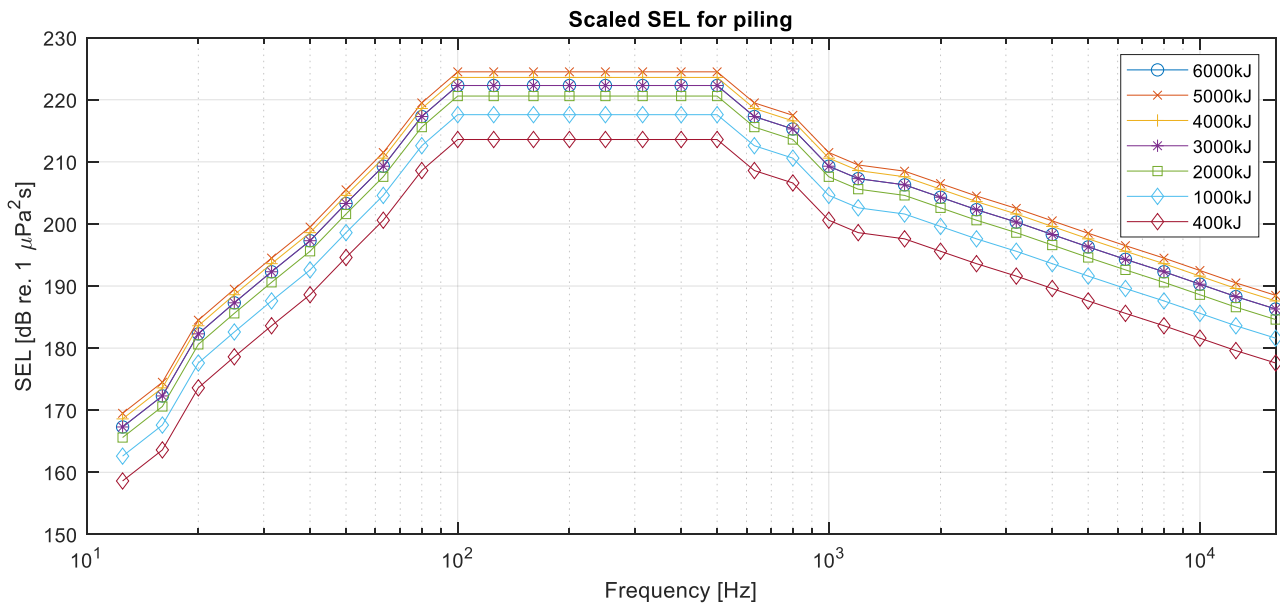
Figure 6-2 - Scaled SEL @ 1 meter for different piling energies.

7 CALCULATION METHODOLOGY

For calculations of sound field from the applicable noise sources, dBSea has been utilized, which is developed by Marshall Day Acoustics and provides support for relatively complex scenarios.

Different methods for calculations of the sound field such as ray-tracing, normal modes and parabolic equation can be used depending on the characteristics of the propagation conditions such as the geometry of the site as well as frequency of the sound. These methods can be combined to account for a broader frequency range. In some cases, simple approximations using spherical attenuation or a combination of spherical and cylindrical attenuation, both combined with frequency dependant attenuation can be utilized in calculations of the sound field.

The propagated sound from the piling was modelled using dbSea, which performs numerical modelling. The sound propagation models used were both normal mode (NM) and acoustic ray-tracing method (RT) complying with DEA's guidelines [6]. The solver utilizes different algorithms in different frequency ranges, i.e., a split solver. The frequency range from 12.5 – 500 Hz is calculated by NM, while RT is used for frequencies f > 500 Hz. The choice of using a split solver is based on [7], and aims to use an optimal solver for each frequency.

A pulse duration of 0.2 seconds is assumed following ISO 18405, to consider a worst-case scenario. The effect of prolonged pulses due to mitigating measures or propagation is not considered.

The source solution is calculated with 36 radial slices and 7000 range points. An example of this is shown in Figure 7-2. The calculation grid is defined to comply with the guidelines [6] which requires a resolution of 20 m resolution in the horizontal plane, and under 1 m resolution in depth resolution. The max length of the transects is ~100km. The values outside the numerical modelling is interpolated. The calculation stops when it reaches the shoreline.

The location of the assumed point source was determined to simulate the worst-case scenarios. Generally, sound propagates further in deeper waters due to reduced interaction with the seabed and sea surface. In Figure 7-1 darker grey indicates deeper water, suggesting that the northern and eastern points at HES represent the worst case. The specific eastern point was selected based on the proximity to the Natura 2000 areas, which are protected habitats of the relevant protected species in Table 9-1., where the WTG position closest to the protected area are indicated.

Due to insufficient research on source modelling for the piling of monopiles, it is assumed that the source behaves as a point source. The point source is further assumed to be at 5 m depth under the assumption that the energy is highest close to the hammer impact, but also considering some lower vibrations at deeper waters.
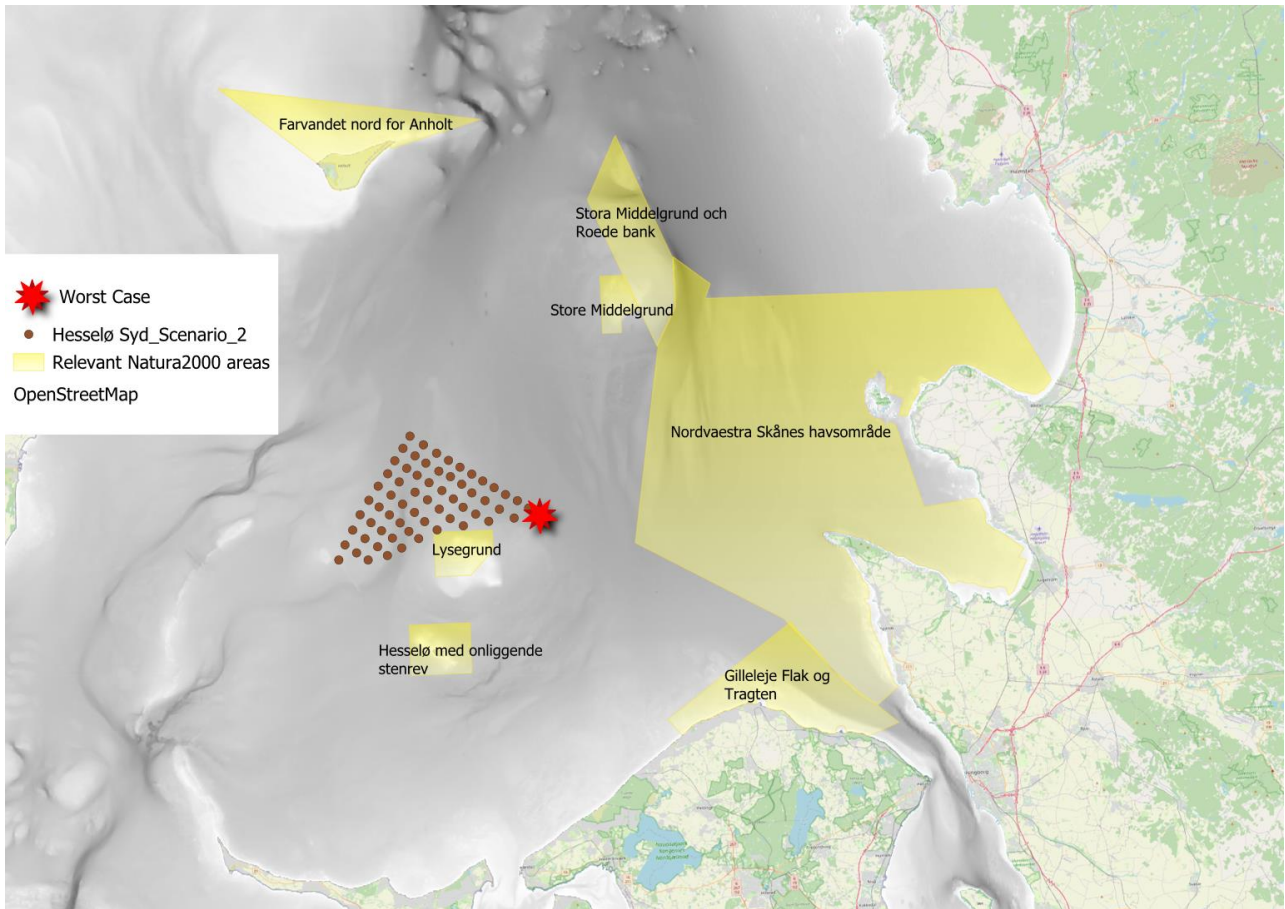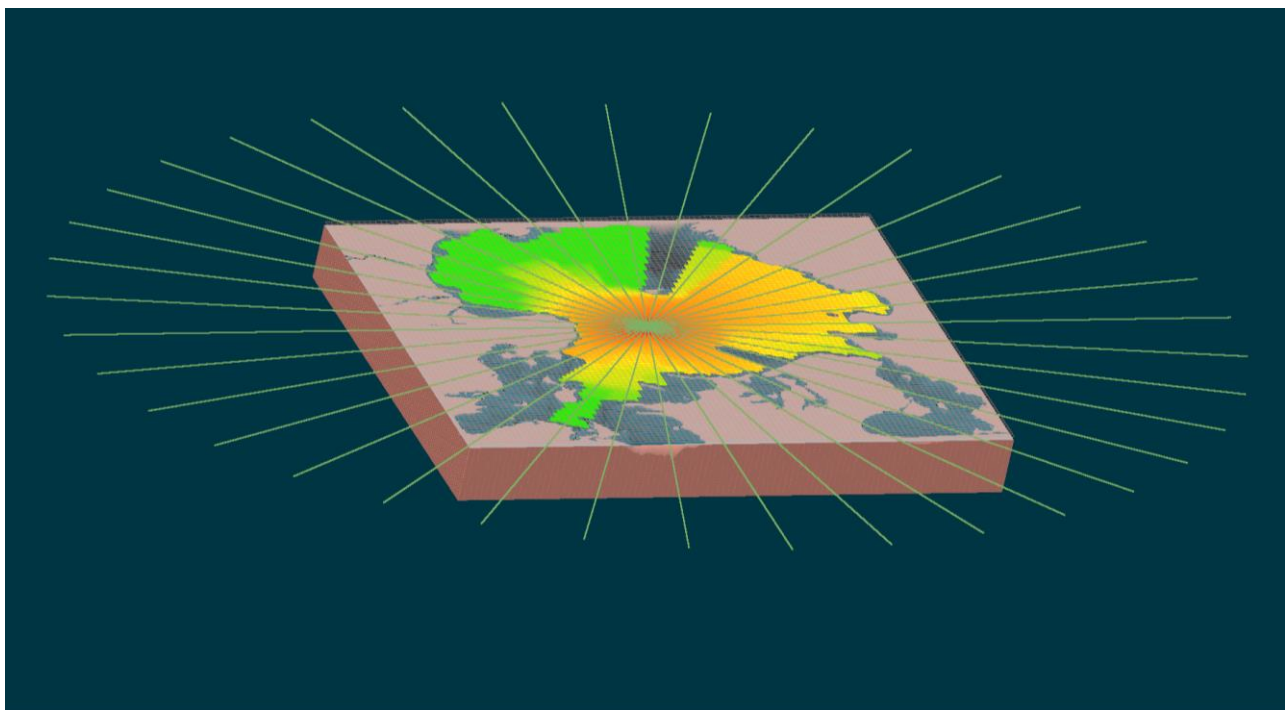
Figure 7-1 - Worst Case Scenario

Figure 7-2 Example figure of calculation grid.

8 OCEAN CHARACTERISTICS

Received data from Energinet shows different seabed-substrate compositions. A single seabed composition assumption must be made for the entire calculated area. The seabed composition is estimated to comprise a 2-meter-thick upper layer of sand, followed by an infinite layer of moraine, based on received data from Energinet. Note that the uncertainty that stems from the seabed composition is relatively small.

The sound speed profile (SSP) is calculated using salinity and temperature data from National Oceanic and Atmospheric Administration (NOAA, 2019). The model used for the sound speed estimation is based on MacKenzie [8].
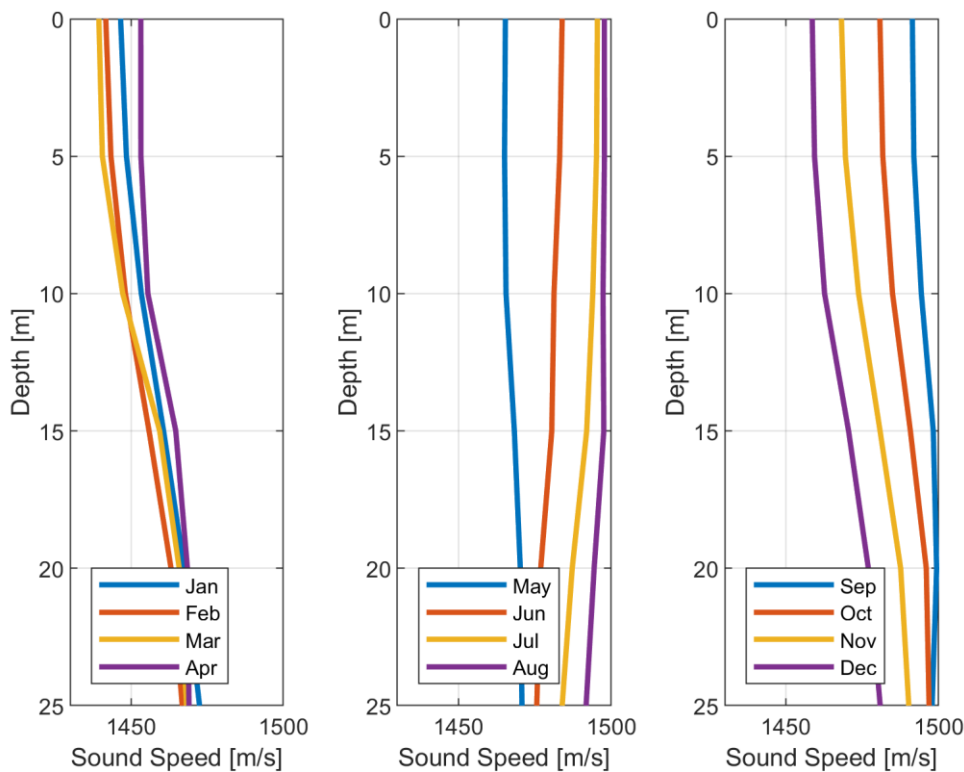
Figure 8-1 - Calculated monthly average sound speed profiles.

Based on received data, the salinity is decided to be on average 32 ppt. The temperature is assumed to be on average 8 degrees through the water column. The pH value is based on typical values for the relevant area.

- Temperature is assumed to be 8°,

- Salinity (ppt) is given as 32,

- pH value is assumed to be 8

The above factors affect the sound absorption in the sea volume. The sound speed profile for a worst-case scenario was determined by running a test model of one of the scenarios, with two different sound speed profiles. The two sound speed profiles represent the edge cases in the sound speed profile. Determining the worst-case was done by checking the resulting sound levels across the calculated grids for the two sound speed profiles. The mean difference between the two resulting grids was 2.64 dB. The sound speed profile of February resulted in the highest sound levels was considered to represent the worst-case scenario.

In the model, the ocean is assumed to have a calm sea state, which results in lower dispersion and therefore the reflection at the sea surface is close to ideal. This means that the largest possible amount of sound energy is reflected at the surface, resulting in a worst-case scenario.

9 AUDITORY FREQUENCY WEIGHTINGS

Following DEA's guidelines [6], the relevant marine species for these oceans are:

- Low frequency (LF) cetaceans

- High frequency (HF) cetaceans

- Very high frequency (VHF) cetaceans

- Phocid carnivores in water (PCW)

The weighting was conducted using dbSEA, which utilizes the weightings as described in Southall [9].

There are three different types of thresholds which are assessed in this report, the Permanent Threshold Shift (PTS), Temporary Threshold Shift (TTS) and Behavioural Disturbance. The thresholds are described in DEA's guidelines [6].

Table 9-1 – Permanent and temporary threshold shift limits and limits for behavioural disturbance for relevant species.

Species	Weighting	Impact Sounds (I-Type)		
		PTS [dB re 1 µPa] SEL_{cum} $L_{E,cum,24h,xx}$	TTS [dB re 1 µPa] SEL_{cum} $L_{E,cum,24h,xx}$	Behavioral Disturbance (BD) [dB re 1 µPa] $L_{p,rms,125\,ms}$
Harbour porpoise	VHF	155	140	103
White-beaked dolphin	HF	185	170	-
Pilot whale				
Minke whale	LF	183	168	-
Harbour seal	PCW	185	170	-
Grey Seal				

10 REFERENCE CASE RESULTS

The reference case is a scenario which represents a practical worst-case scenario without noise mitigating measures. The goal is to determine the magnitude of noise reduction needed for a mammal to be able to have a starting position of 200 m from the piling, and still be exposed to less noise than corresponding to the PTS criteria.

The SEL_{cum} has been calculated with appropriate frequency weightings and compared to the PTS levels in Table 9-1, presented with required noise mitigation to comply with the PTS levels. This is calculated for both diameters and hammer sequences, and the results are shown in Table 10-1 to Table 10-4.

The position was chose based on the worst-case scenario, shown in Figure 7-1. The maximum required noise reduction by mitigating measures was calculated to be 17.4 dB.

Table 10-1: 6000 kJ 13 m

Species	Weighting	SEL_{cum} $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 13 m [dB]
Harbour porpoise	VHF	155.7	0.7
White-beaked dolphin	HF	162.0	0
Pilot whale			
Minke whale	LF	196.4	16.4
Harbour seal	PCW	185.2	0.2
Grey seal			

Table 10-2: 6000 kJ 15 m

Species	Weighting	SEL_{cum} $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 15 m [dB]
Harbour porpoise	VHF	156.7	1.7
White-beaked dolphin	HF	163.0	0
Pilot whale			
Minke whale	LF	197.4	17.4
Harbour seal	PCW	186.2	1.2
Grey seal			

Table 10-3: 4000 kJ 13 m

Species	Weighting	SEL_{cum} $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 13 m [dB]
Harbour porpoise	VHF	154.8	0
White-beaked dolphin	HF	160.9	0
Pilot whale			
Minke whale	LF	194.5	11.5
Harbour seal	PCW	183.5	0
Grey seal			

Table 10-4: 4000 kJ 15 m

Species	Weighting	SEL_{cum} $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 15 m [dB]
Harbour porpoise	VHF	155.9	0.9
White-beaked dolphin	HF	161.9	0
Pilot whale			
Minke whale	LF	195.5	12.5
Harbour seal	PCW	184.5	0
Grey seal			

11 CONSTRUCTION CASE WITH MITIGATION MEASURES

The following represents a realistic scenario of the planned installation of monopiles in HES OWF. It assumes the piling to be the only active noise source. The goal is to determine a distance-to-threshold (DTT) corresponding to PTS, TTS and BD criteria, denoted as r_{PTS}, r_{TTS} and r_{BD}. The DTT's were calculated with and without noise mitigating measures, based on a model where a marine mammal starts at 50 meters from the source and flees directly away at a speed of 1.5 m/s.

The DEA guidelines state that before any pile driving activity begins, there must be a designated distance within which no animals are present, denoted as r_{safe}, which shall be assumed. Assuming a use of an acoustic deterrent device (ADD) for 15 minutes, the assumed r_{safe} is 15 minutes times the estimate fleeing speed of an animal of 1.5 m/s, corresponding to 1350 meters. Since $r_{\text{PTS}} > r_{\text{safe}}$, there will be need for damping measures for all the scenarios presented. Two typical noise mitigating measures are a double bubble curtain (DBBC) and a hydro sound damper (HSD). The effect of the DBBC depends on the density and size of the bubbles. According to Bellmann [10], the effect of a DBBC is assumed to be minimum 8 dB, and the minimum effect from HSD can be assumed to be 10 dB. These will be the proposed noise mitigating measures during the piling operation, with a combined effect of 18 dB. The results are presented in Table 11-1 - Table 11-8. These include the r_{PTS}, r_{TTS} and r_{BD} for the species described in Table 9-1. Some example figures of the modelling are presented in Appendix B.

In general, the results indicate that the auditory group LF will have the longest r_{PTS} and r_{TTS} of the different hearing groups when noise mitigating measures are taken into account. Note that according to the modelling results the 6000 kJ hammer with a 13 m diameter generates a higher noise level than the 4000 kJ hammer with a 15 m diameter. According to the DEA's guidelines, piling is permitted only if $r_{\text{PTS}} < r_{\text{safe}}$. As seen in Table 11-1 through Table 11-8, $r_{\text{PTS}} < r_{\text{safe}}$ for all configurations. Additionally, piling is allowed without the use of an ADD since all r_{PTS} values are less than 50 m, concurring with DEA's guideline of $r_{\text{PTS}} < 200$ m.

Table 11-1: Worst case r_PTS and r_TTS for relevant species with 6000 kJ hammer and 15 m pile diameter.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	630	23810	<50	90
White-beaked dolphin	HF	<50	<50	<50	50
Pilot whale					
Minke whale	LF	67510	96610	<50	44290
Harbour seal	PCW	1130	70930	<50	<50
Grey seal					

Table 11-2: Worst case r_{BD} for VHF species with 6000 kJ hammer and 15 m pile diameter.

Species	Weighting	No damping	DBBC + HSD
		r_{BD}[m]	r_{BD}[m]
Harbour porpoise	VHF	75077	18809

Table 11-3: Worst case r_PTS and r_TTS for relevant species for hammer with 6000 kJ and 13 m pile diameter.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	330	20170	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	63050	95910	<50	39130
Harbour seal	PCW	290	67970	<50	<50
Grey seal					

Table 11-4: Worst case r_{BD} for VHF species for relevant species for hammer with 6000 kJ and 13 m pile diameter.

Species	Weighting	No damping	DBBC + HSD
		r_{BD}[m]	r_{BD}[m]
Harbour porpoise	VHF	88046	17270

Table 11-5: Worst case r_PTS and r_TTS for relevant species for hammer with 4000 kJ and 15 m pile diameter.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	330	16510	<50	70
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	50070	94310	<50	29990
Harbour seal	PCW	90	58250	<50	<50
Grey seal					

Table 11-6: Worst case r_{BD} for VHF species for relevant species for hammer with 4000 kJ and 15 m pile diameter.

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	62486	12937

Table 11-7: Worst case r$_{PTS}$ and r$_{TTS}$ for relevant species for hammer with 4000 kJ and 13 m pile diameter

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	190	14490	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	40630	92410	<50	24330
Harbour seal	PCW	<50	51510	<50	<50
Grey seal					

Table 11-8: Worst case r_{BD} for VHF species for relevant species for hammer with 4000 kJ and 13 m pile diameter.

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD} [m]
Harbour porpoise	VHF	56834	12777

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APPENDIX A
Table A-1 Proposed Coordinates of HES OWF

Turbine type : 20MW		
Coordinate system : UTM (North) WGS 84 : Zone 33	**Turbines**	**MW**
	63	1260
Hesselø		
User label	**Easting**	**Northing**
1	284916	6244664
2	288345	6244366
3	287072	6245316
4	285794	6246362
5	290644	6244693
6	289593	6245822
7	288198	6246895
8	286849	6248019
9	292399	6245420
10	291407	6246683
11	290209	6247650
12	289058	6248699
13	287875	6249740
14	294473	6246353
15	293401	6247292
16	292464	6248382
17	291301	6249421
18	290169	6250448
19	289043	6251337
20	296722	6247183
21	295347	6248273
22	294255	6249456
23	292946	6250544
24	291684	6251714
25	290273	6252892
26	299823	6247389
27	298358	6248366
28	297182	6249595
29	295899	6250797
30	294532	6251813
31	292780	6253176
32	291524	6254250
33	302844	6247659
34	301389	6248634
35	299986	6249564
36	298930	6250638
37	297683	6251732
38	296255	6252781
39	294940	6253763
40	293792	6254694
41	292479	6255696
42	305845	6247777
43	304220	6248960
44	302624	6250112
45	301162	6251150
46	300054	6252269
47	298824	6253266

| Turbine type : 20MW		
Coordinate system : UTM (North) WGS 84 : Zone 33	**Turbines**	**MW**
	63	1260
Hesselø		
User label	**Easting**	**Northing**
48	297519	6254023
49	296082	6255105
50	294893	6256059
51	293557	6257062
52	308869	6247847
53	307645	6248799
54	306403	6249774
55	305079	6250614
56	303812	6251537
57	302555	6252428
58	301342	6253349
59	300034	6254276
60	298758	6255190
61	297441	6256150
62	294504	6258415
63	295987	6257270

APPENDIX B
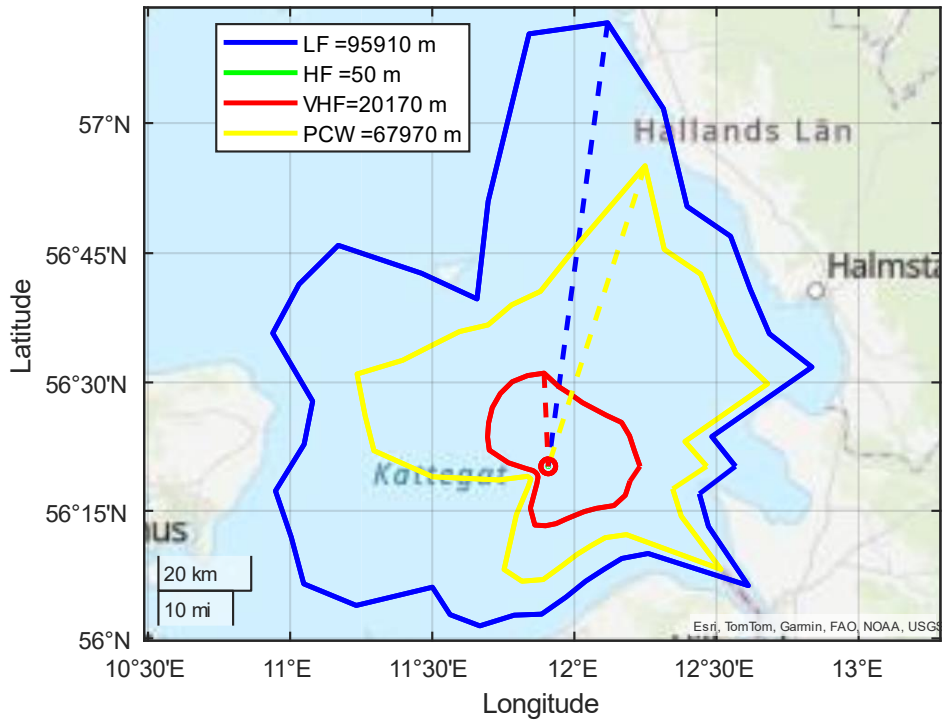
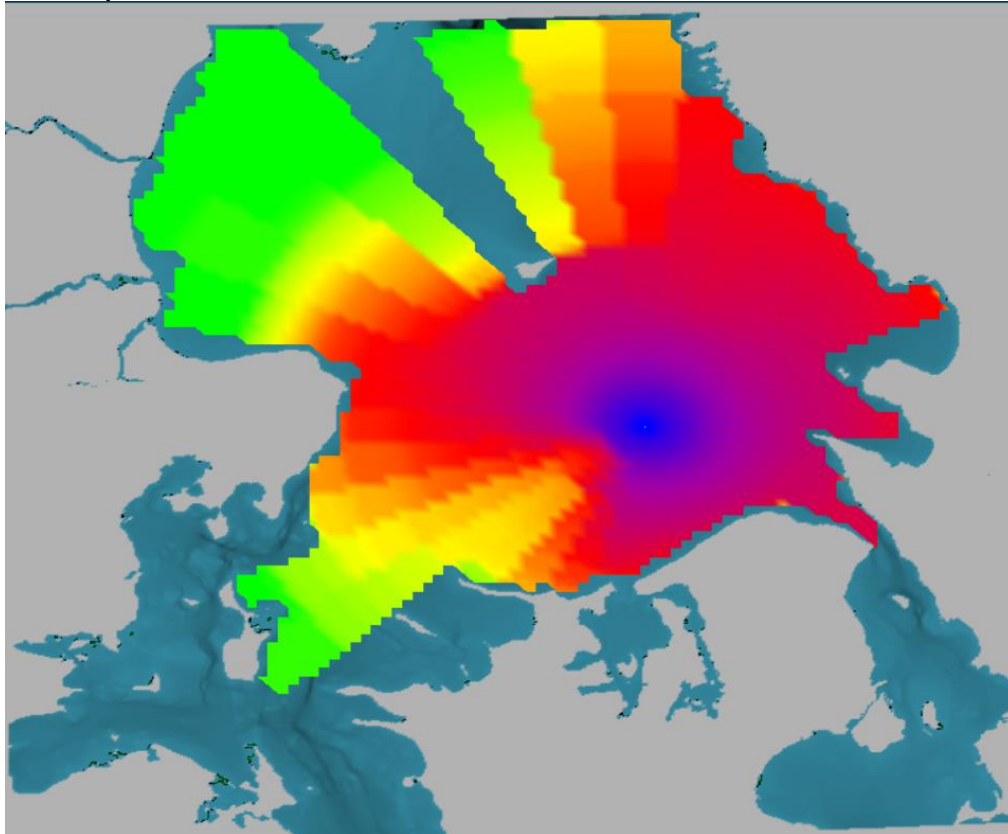**Figure B-1 Noise map with different DTT's for TTS with 6000 kJ Hammer and 13 diameter without damping**

Figure B-2 Visualization of Sound Field

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.