TECHNICAL REPORT OF KF OWF 2030

Underwater Noise Kriegers Flak 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
HSD	Hydro Sound Damper
KF	Kriegers Flak
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

DNV's section for noise and vibration, Commissioned by Energinet, has carried out an assessment of the underwater noise generated by installation of foundations of wind turbines for Kriegers Flak (KF) offshore wind farm (OWF). KF is divided into two areas, henceforth written as KF North and KF South.

In order to accelerate the expansion of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided), that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concession winners – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

In order to enable the realization of the political agreements on significantly more energy production from offshore wind before the end of 2030, the Danish Energy Agency has drawn up a plan for the establishment of offshore wind farms in three areas in the North Sea, the Kattegat and the Baltic Sea respectively.

The area for Kriegers Flak II Offshore Wind Farm (OWF) consists of two sub-areas: North and South. The areas are located 25-50 km off the coast of South Zealand and Møn. Kriegers Flak II North is located approximately 15 km from the east coast of Møn, while Kriegers Flak II South is located approximately 30 km southeast of Møn. The area for the Kriegers Flak II OWF is approximately 175 km^2, divided into 99km^2 for the northern and 76km^2 for southern part of the OWF. The Kriegers Flak II OWF will be connected to land via subsea cables making landfall close to Rødvig on South Zealand.

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 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 mitigation 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 13.1 dB. Conversely, the 18-meter monopile needs a reduction of up to 15.4 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 order to accelerate the expansion of Danish offshore wind production, it was decided with the agreement on the Finance Act for 2022 to offer an additional 2 GW of offshore wind for establishment before the end of 2030. In addition, the parties behind the Climate Agreement on Green Power and Heat 2022 of 25 June 2022 (hereinafter Climate Agreement 2022) decided), that areas that can accommodate an additional 4 GW of offshore wind must be offered for establishment before the end of 2030. Most recently, a political agreement was concluded on 30 May 2023, which establishes the framework for the Climate Agreement 2022 with the development of 9 GW of offshore wind, which potentially can be increased to 14 GW or more if the concession winners – i.e. the tenderers who will set up the offshore wind turbines – use the freedom included in the agreement to establish capacity in addition to the tendered minimum capacity of 1 GW per tendered area.

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The area for Kriegers Flak II Offshore Wind Farm (OWF) consists of two sub-areas: North and South. The areas are located 25-50 km off the coast of South Zealand and Møn. Kriegers Flak II North is located approximately 15 km from the east coast of Møn, while Kriegers Flak II South is located approximately 30 km southeast of Møn. The area for the Kriegers Flak II OWF is approximately 175 km2, divided into 99km2 for North and 76km2 for South. The Kriegers Flak II OWF will be connected to land via subsea cables making landfall close to Rødvig on South Zealand.

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 name of the planned OWF in the western Baltic is Kriegers Flak II. The OWF consist of two areas, KF II North and KF II South and is located southern Baltic Sea. The windfarm layouts of Kriegers Flak is presented in Figure 3-1, and represents overplanting scenarios. The specific coordinates can be found in Appendix A.

The report follows DEA's guidelines for underwater noise, and its requirement to include two cases. The first case is the reference case, where the calculated results based on installation without use of noise mitigating measures are 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 can be found in DEA's guidelines.

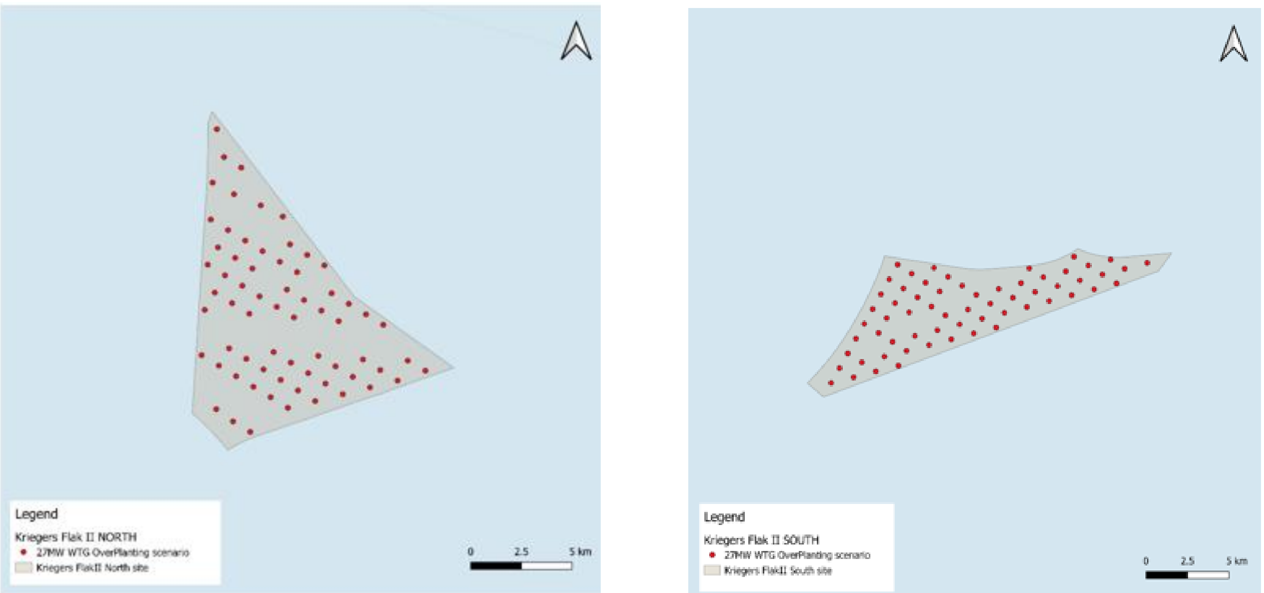


Figure 3-1 OWF Layout for KF North & South (UTM Zone 33N).

4 MAIN PARTICULARS OF OWF

For the KF II 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	175 km^2 (North 99 km^2 & South 76 km^2)
Name of OWF	Kriegers Flak North & South
Nameplate Capacity	15 MW 27 MW
Underwater noise regulation	DEA Guideline for Underwater Noise [2]
Foundation	
Type	Monopiles
Diameter (15 MW)	13 m
Diameter (20 MW)	18 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 ms 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.

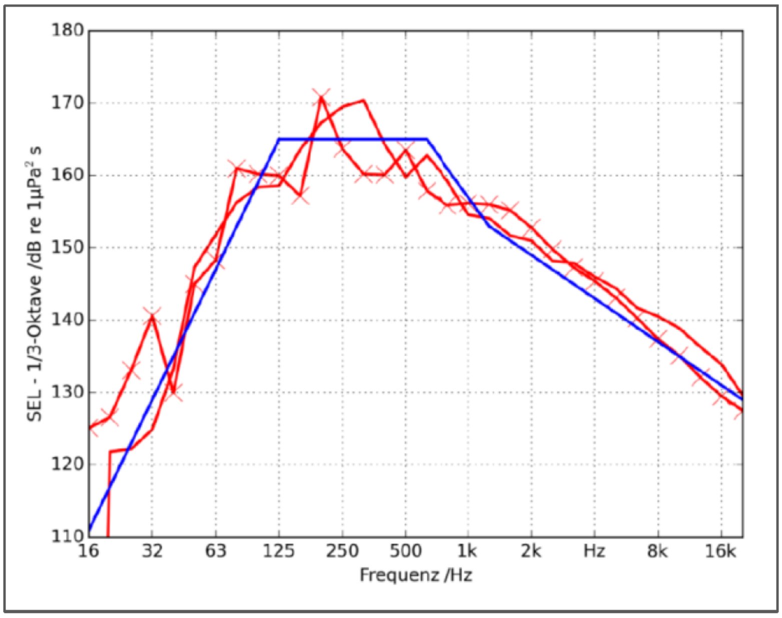


Figure 6-1 – SEL 1/3 – Octave band reference values [4]

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

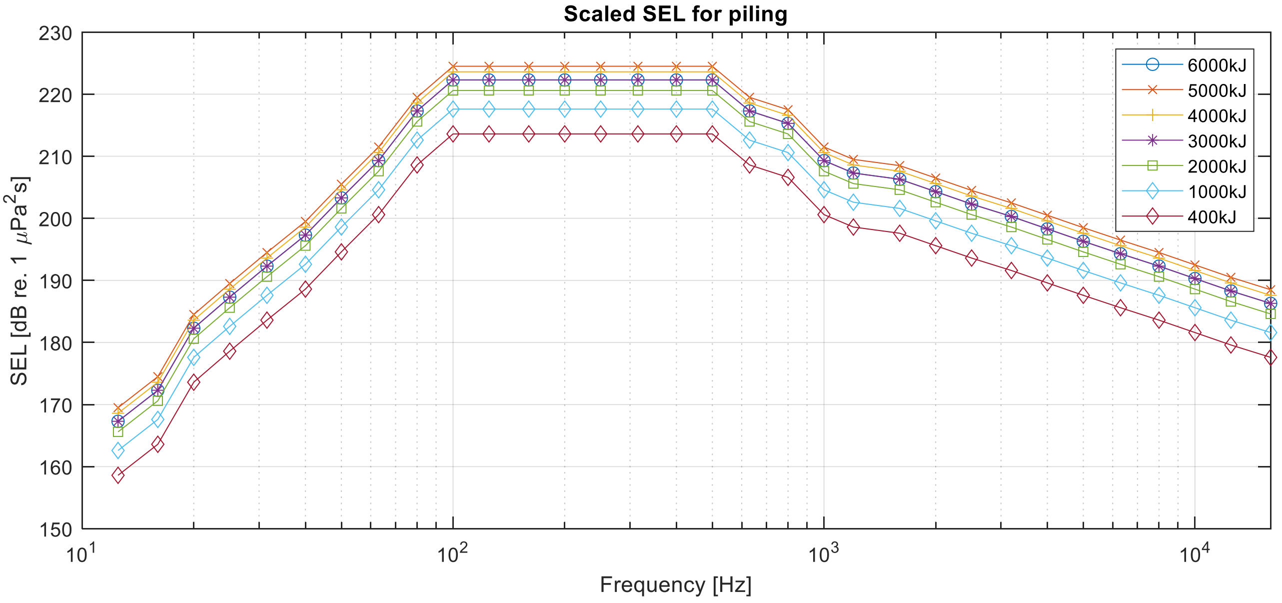


Figure 6-2 - Scaled SEL @ 1 meter for different piling energies.

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.

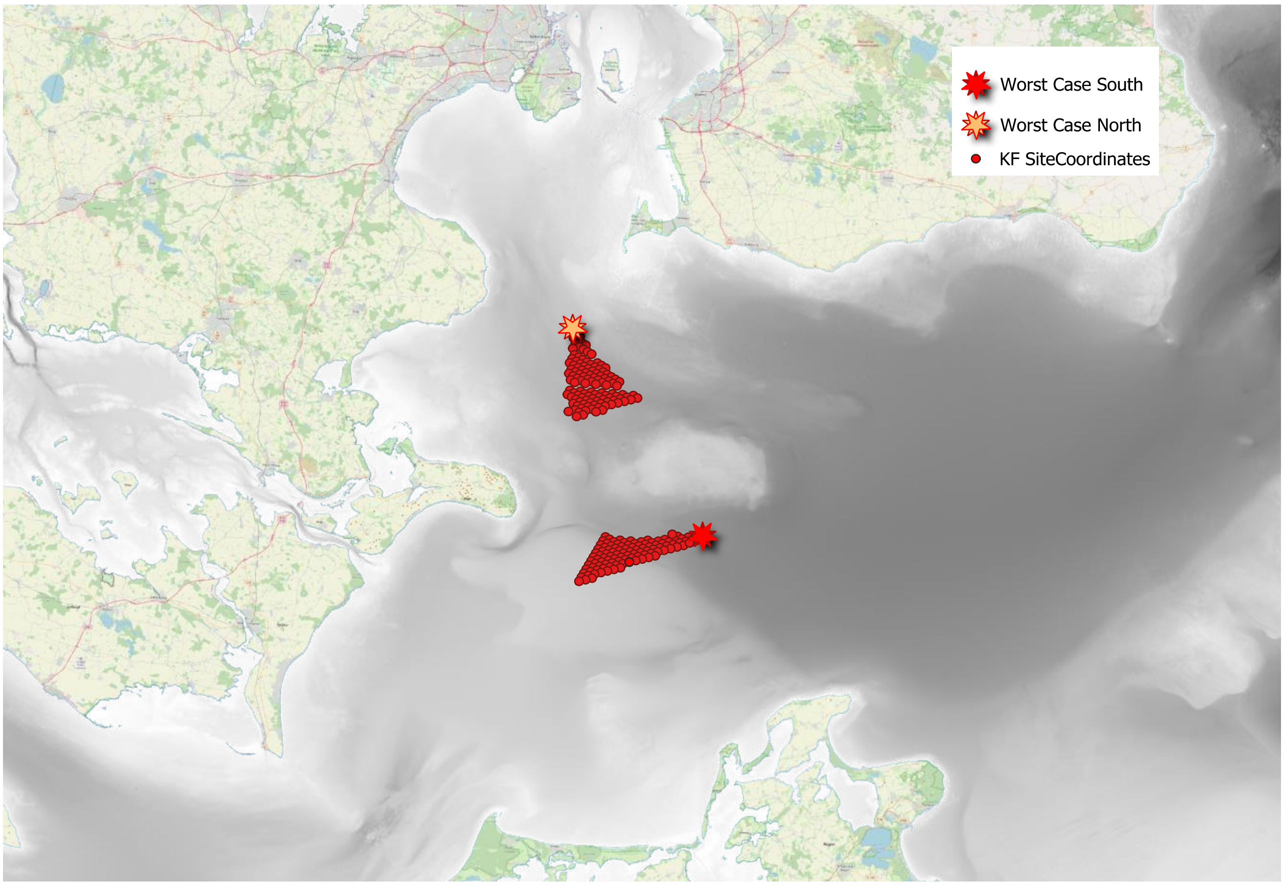
Different methods for calculations of the sound field such as ray-tracing, normal modes and parabolic equation can be used depending on the characteristics of the propagation conditions such as the geometry of the site as well as frequency of the sound. These methods can be combined to account for a 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. 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 ~200km. 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. The northern worst case was based on Kriegers Flak Offshore Wind Farm Environmental Statement made by Energistyrelsen [8]. Chapter 5.5 in [8] shows geotracking of Harbour Seals that showcase that the southeastern coast of Sweden serves as a habitat for harbour seals. Therefore, the northernmost positions were chosen. The selection of the southern worst-case position was based on the increasing depth of the seabed, resulting in reduced energy loss from seabed reflection, thus representing a worst-case scenario.



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.

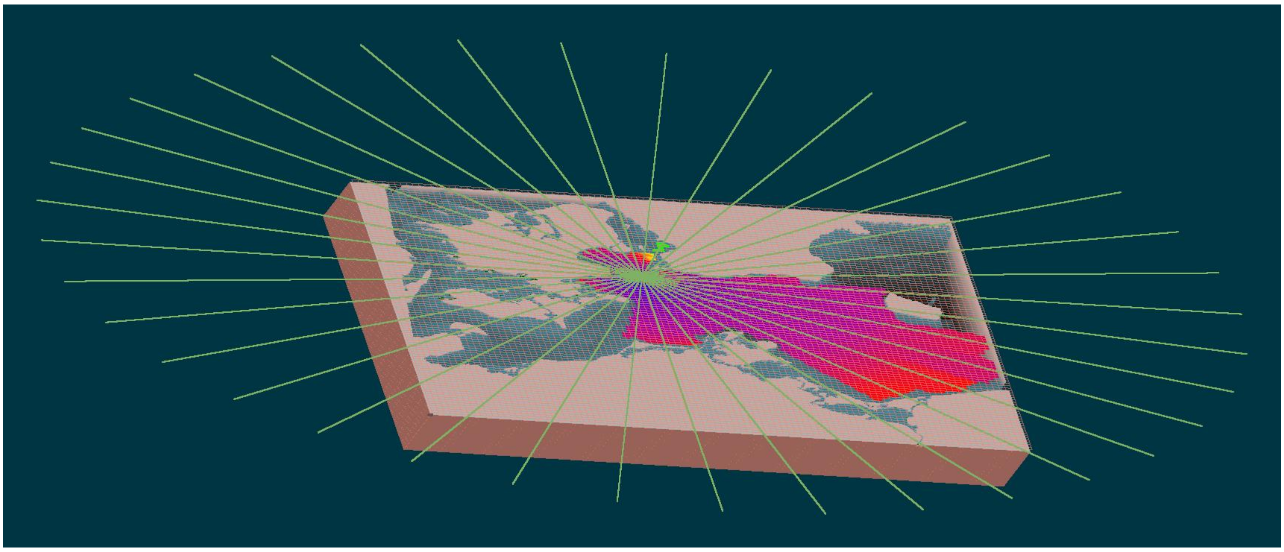


Figure 7-2 Example figure of calculation grid.

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.

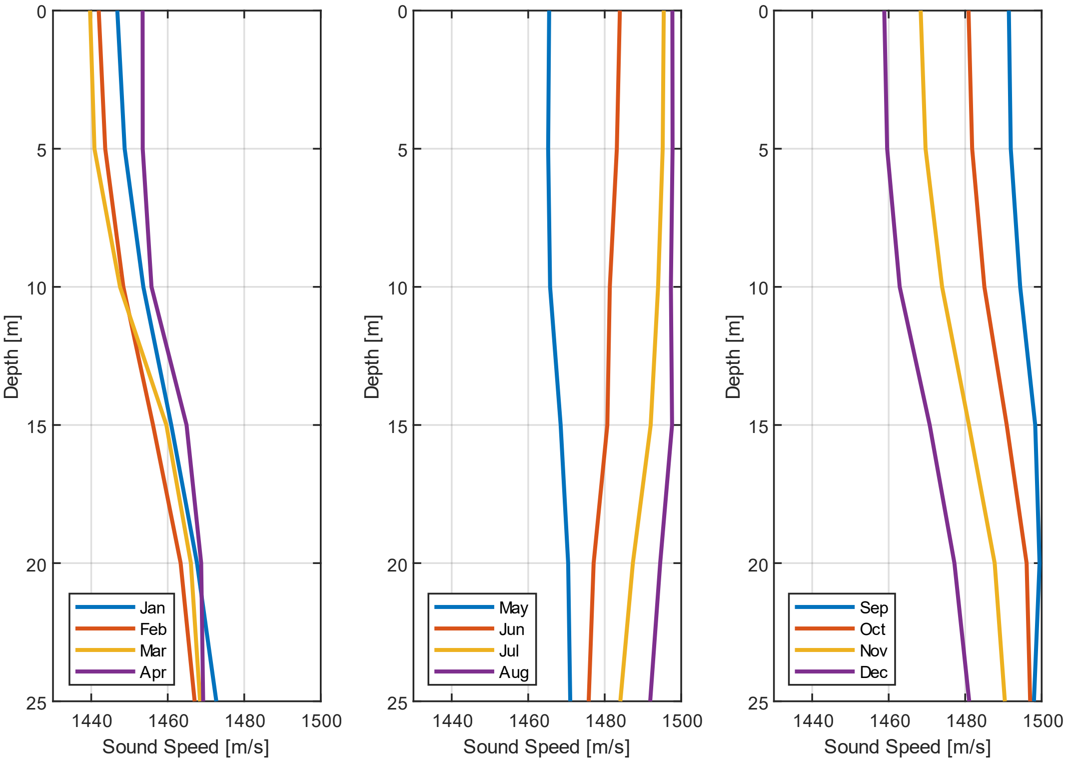


Figure 8-1 Calculated monthly average sound speed profiles

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 [9].

Bases 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 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 [10].

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] $\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	TTS [dB re 1 µPa] $\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	Behavioral Disturbance (BD) [dB re 1 µPa] $L_{\mathrm{p,rms,125\ ms}}$
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 the corresponding PTS criteria.

The $\mathbf{SEL_{cum}}$ 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 **10-8.**

The position was chosen based on the worst-case scenario, shown in Figure 7-1. The maximum required noise reduction by mitigating measures was determined to be 15.4 dB.

Table 10-1: 6000 kJ 13 m for KF South

Species	Weighting	$\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 13 m [dB]
Harbour porpoise	VHF	155.5	0.5
White-beaked dolphin	HF	161.8	0
Pilot whale			
Minke whale	LF	196.1	13.1
Harbour seal	PCW	184.9	0
Grey seal			

Table 10-2: 6000 kJ 18 m for KF South

Species	Weighting	$\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 18 m [dB]
Harbour porpoise	VHF	157.8	2.8
White-beaked dolphin	HF	164.1	0
Pilot whale			
Minke whale	LF	198.4	15.4
Harbour seal	PCW	187.2	2.2
Grey seal			

Table 10-3: 4000 kJ 13 m for KF South

Species	Weighting	$\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 13 m [dB]
Harbour porpoise	VHF	154.4	0
White-beaked dolphin	HF	160.4	0
Pilot whale			
Minke whale	LF	194.1	11.1
Harbour seal	PCW	183.0	0
Grey seal			

Table 10-4: 4000 kJ 18 m for KF South

Species	Weighting	$\mathrm{SEL_{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 18 m [dB]
Harbour porpoise	VHF	156.8	1.8
White-beaked dolphin	HF	162.8	0
Pilot whale			
Minke whale	LF	196.4	13.4
Harbour seal	PCW	185.4	0.4
Grey seal			

Table 10-5 6000 kJ 13 m for KF North

Species	Weighting	SEL$_{\text{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 13 m [dB]
Harbour porpoise	VHF	155.0	0
White-beaked dolphin Pilot whale	HF	181.3	0
Minke whale	LF	195.5	12.5
Harbour seal Grey seal	PCW	184.4	0

Table 10-6 6000 kJ 18 m for KF North

Species	Weighting	SEL$_{\text{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 6000 kJ 18 m [dB]
Harbour porpoise	VHF	157.4	2.4
White-beaked dolphin Pilot whale	HF	163.6	0
Minke whale	LF	197.9	14.9
Harbour seal Grey seal	PCW	186.7	1.7

Table 10-7 4000 kJ 13 m for KF North

Species	Weighting	SEL$_{\text{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 13 m [dB]
Harbour porpoise	VHF	154.3	0
White-beaked dolphin Pilot whale	HF	160.3	0
Minke whale	LF	193.7	10.7
Harbour seal Grey seal	PCW	182.8	0

Table 10-8 4000 kJ 18 m for KF North

Species	Weighting	SEL$_{\text{cum}}$ $L_{E,cum,24h,xx}$	Required Noise Mitigation 4000 kJ 18 m [dB]
Harbour porpoise	VHF	156.7	1.7
White-beaked dolphin Pilot whale	HF	162.7	0
Minke whale	LF	196.0	13
Harbour seal Grey seal	PCW	185.1	0.1

11 CONSTRUCTION CASE WITH MITIGATION MEASURES

The following represents a realistic scenario of the planned installation of monopiles in Kriegers Flak 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 given in Table 9-1, denoted as r_{PTS}, r_{TTS} and r_{BD}. The DTT's were calculated with and without noise mitigations 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 $r_{\mathrm{PTS}} > r_{\mathrm{safe}}$, 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 [11], 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 11-16. 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}. According to the DEA's guidelines, piling is permitted only if $r_{\mathrm{PTS}} < r_{\mathrm{safe}}$. As shown in Table 11-1 through Table 11-16, $r_{\mathrm{PTS}} < r_{\mathrm{safe}}$ 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 $r_{\mathrm{PTS}} < 200$ m.

Table 11-1: Worst case r_{PTS} and r_{TTS} for relevant species with 6000 kJ hammer and 18 m pile diameter for KF South.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	1450	35150	<50	190
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	88650	169470	<50	70290
Harbour seal	PCW	3090	97150	<50	<50
Grey seal					

Table 11-2: Worst case r_{BD} for VHF species with 6000 kJ hammer and 18 m pile diameter for KF South.

Species	Weighting	No damping	DBBC + HSD
		r_{BD}[m]	r_{BD}[m]
Harbour porpoise	VHF	81985	15637

Table 11-3: Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 6000 kJ and 13 m pile diameter for KF South.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	310	23650	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	73890	167430	<50	47910
Harbour seal	PCW	150	80110	<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 for KF South.

Species	Weighting	No damping	DBBC + HSD
		r_{BD}[m]	r_{BD}[m]
Harbour porpoise	VHF	70995	12560

Table 11-5: Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 4000 kJ and 18 m pile diameter for KF South.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	590	23430	<50	110
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	72850	166650	<50	48390
Harbour seal	PCW	350	80070	<50	<50
Grey seal					

Table 11-6: Worst case r_{BD} for VHF species for relevant species for hammer with 4000 kJ and 18 m pile diameter for KF South.

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	61261	10613

Table 11-7: Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 4000 kJ and 13 m pile diameter for KF South.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	150	16550	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	54970	161720	<50	27150
Harbour seal	PCW	<50	63890	<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 for KF South.

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	45122	8666

Table 11-9 Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 6000 kJ and 18 m pile diameter for KF North.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	790	22310	<50	150
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	95210	194690	<50	53190
Harbour seal	PCW	1610	108170	<50	<50
Grey Seal					

Table 11-10 : Worst case r_{BD} for VHF species for relevant species for hammer with 6000 kJ and 18 m pile diameter for KF North

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	90746	12780

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

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	210	15330	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	61130	192710	<50	29950
Harbour seal	PCW	70	78610	<50	<50
Grey seal					

Table 11-12 Worst case r_{BD} for VHF species for relevant species for hammer with 6000 kJ and 13 m pile diameter for KF North

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	75486	10896

Table 11-13 Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 4000 kJ and 18 m pile diameter for KF North.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	470	15430	<50	110
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	62210	191990	<50	29970
Harbour seal	PCW	230	80110	<50	<50
Grey seal					

Table 11-14 Worst case r_{BD} for VHF species for relevant species for hammer with 4000 kJ and 18 m pile diameter for KF North

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	52218	9231

Table 11-15 Worst case r_{PTS} and r_{TTS} for relevant species for hammer with 4000 kJ and 13 m pile diameter for KF North.

Species	Weighting	No damping		DBBC + HSD	
		r_{PTS} [m]	r_{TTS} [m]	r_{PTS} [m]	r_{TTS} [m]
Harbour porpoise	VHF	120	11190	<50	<50
White-beaked dolphin	HF	<50	<50	<50	<50
Pilot whale					
Minke whale	LF	35350	186170	<50	16710
Harbour seal	PCW	<50	48490	<50	<50
Grey Seal					

Table 11-16 Worst case r_{BD} for VHF species for relevant species for hammer with 4000 kJ and 13 m pile diameter for KF North

Species	Weighting	No damping	DBBC + HSD
		r_{BD} [m]	r_{BD}[m]
Harbour porpoise	VHF	34571	7599

12 REFERENCES

[1] M. Bellmann, A. May, T. Wendt, S. Gerlach, P. Remmers and J. Brinkmann, “Underwater noise during percussice pile driving,” ITAP, 2020.

[2] ISO, “Underwater acoustics - Terminology,” *ISO,* no. 1, 2017.

[3] J. v. Pein, “Scaling laws for unmitigated pile driving: Dependence of underwater,” *Applied Acoustics 198,* 2022.

[4] M. Bellmann and J. Brinkmann, “Noise mitigation ofr large foundations (Moopile L& Xl) - Technical ptions for complying with noise limits, Noise mitigation ofr the constrctuion of increasingly large offshore wind turbines.,” 2018.

[5] R. Thiele, “Propagation loss values for the North Sea. Handout Fachgespräch: Offshore-Windmillssound emissions and marine mammals,” 2002.

[6] DEA, Danish Energy Agency, “Guideline for underwater noise,” 2022.

[7] P. C. Etter, “Review of Ocean - Acoustic Models,” Norhtrop Grumman Corporation - Electronic Systems, Baltimore, Maryland.

[8] NIRAS A/S and COWI A/S, “Kriegers Flak Offshore Wind Farm: Environmental Statement,” Governmental, 2015.

[9] J. M. Hovem, Marine Acoustics - The Physics of Sound in Underwater Environments, Los Altos Hills: Peninsula Publishing, 2012.

[10] B. L. Southall, J. J. Finneran, C. Reichmuth, P. E. Nachtigall, D. R. Ketten, A. E. Bowles, W. T. Ellison, D. P. Nowacek and P. L. Tyack, “Marine Mammal Noise Exposure Criteria: Updated Scientifific Recommendations for Residual Hearing Effects,” 2019.

[11] D. M. A. Bellmann, “Underwater noise during percussive pile driving:,” Oldenburg, 2020.

[12] G. G. R. Francois R. E., “Sound absorption based on ocean measurements: Part II:Boric acid contribution and equation for total absorption,” *Journal of the Acoustical Society of America,,* vol. 72, pp. 1879-1890, 1982.

APPENDIX A

Table A-1 Proposed Coordinates of KF OWF

Turbine type : 27MW					
Coordinate system : UTM (North) WGS 84 : Zone 33					
	Turbines	MW			
NORTH	36	972			
SOUTH	30	810			
	66	**1782**			
Kriegers Flak II (NORTH)			**Kriegers Flak II (SOUTH)**		
User label	**Easting**	**Northing**	**User label**	**Easting**	**Northing**
KFN-1	352517	6124081	KFS-1	354698	6082189
KFN-2	352524	6122586	KFS-2	355491	6083587
KFN-3	352497	6121079	KFS-3	353612	6080747
KFN-4	352351	6119577	KFS-4	356349	6084938
KFN-5	352314	6118070	KFS-5	357651	6087767
KFN-6	352145	6116545	KFS-6	355713	6080968
KFN-7	352086	6115049	KFS-7	357655	6083778
KFN-8	352027	6113542	KFS-8	357053	6086317
KFN-9	351892	6112058	KFS-9	356811	6082234
KFN-10	353648	6111091	KFS-10	358469	6085163
KFN-11	353821	6112646	KFS-11	359131	6086584
KFN-12	353950	6114181	KFS-12	361252	6086837
KFN-13	354015	6115750	KFS-13	360525	6085399
KFN-14	354098	6117230	KFS-14	359815	6083871
KFN-15	354270	6118739	KFS-15	361876	6084249
KFN-16	354301	6120297	KFS-16	358890	6082538
KFN-17	354332	6121821	KFS-17	363306	6087097
KFN-18	356081	6119416	KFS-18	361380	6082879
KFN-19	355966	6117825	KFS-19	364669	6085958
KFN-20	355877	6116374	KFS-20	365788	6087298
KFN-21	355776	6114890	KFS-21	363996	6084405
KFN-22	355757	6113239	KFS-22	366034	6084795
KFN-23	355568	6111746	KFS-23	366735	6086103
KFN-24	355422	6110208	KFS-24	367962	6087340
KFN-25	357681	6117082	KFS-25	368842	6085787
KFN-26	357688	6115518	KFS-26	369587	6088280
KFN-27	357499	6114004	KFS-27	369954	6086885
KFN-28	357505	6112418	KFS-28	371569	6087859
KFN-29	357316	6110903	KFS-29	362701	6085597
KFN-30	353224	6109361	KFS-30	373600	6087591
KFN-31	359389	6114634			
KFN-32	359458	6112937			
KFN-33	359238	6111467			
KFN-34	361216	6113843			
KFN-35	361136	6111932			
KFN-36	363222	6112379			

APPENDIX B

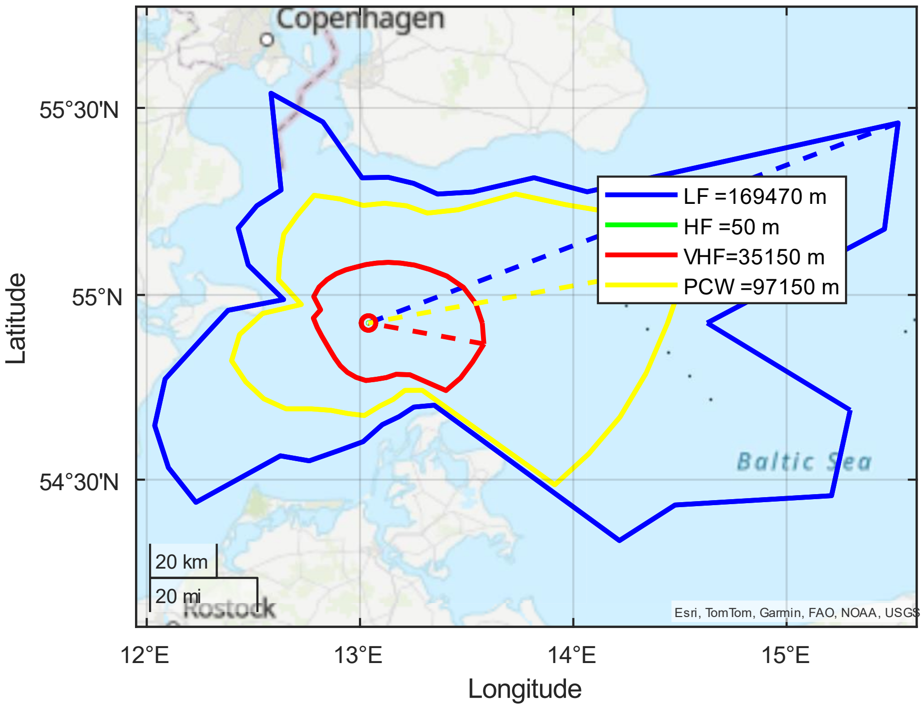


Figure B-1 Noise map with different DTT's for TTS with 6000 kJ Hammer and 18 diameter without damping

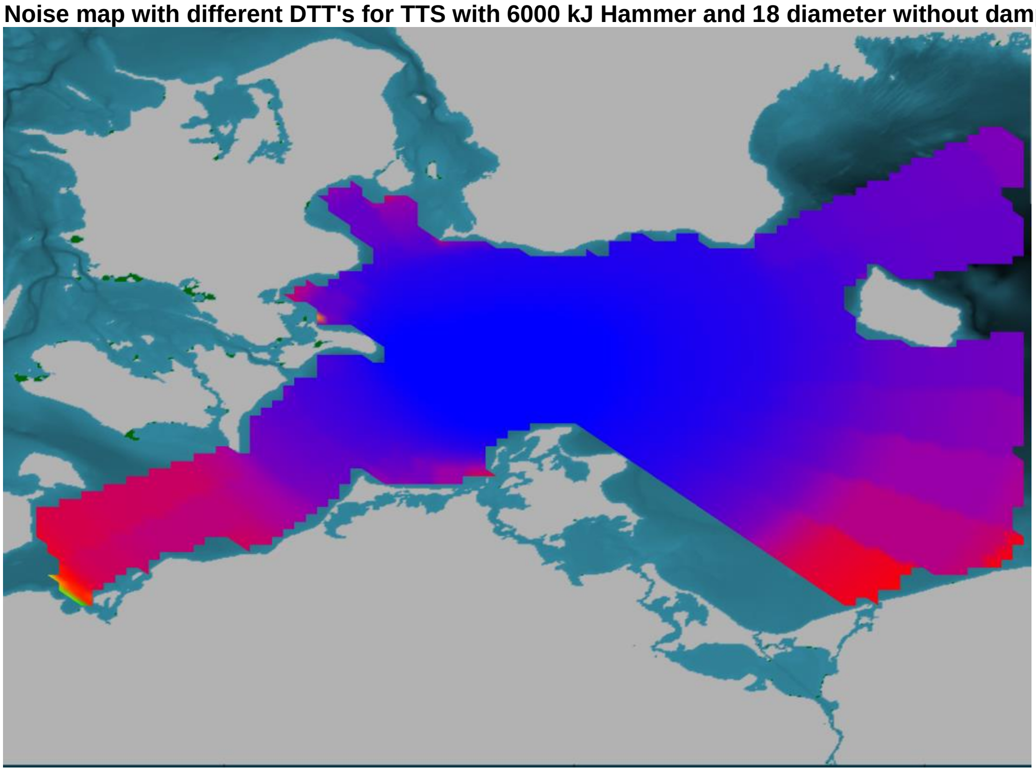


Figure B-2 Visualization of Sound Field

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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.

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