Underwater Noise

Social Cost Benefit Analysis

Rijkswaterstaat

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Final Report

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MANAGEMENT SUMMARY

The European Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) of the European maritime waters by 2020 (EU, 2008). GES is defined in terms of eleven descriptors, one of which is underwater noise (descriptor 11). The MSFD calls for Member States to identify measures to be taken to achieve or maintain Good Environmental Status (Article 13/1), but also to "ensure that measures are cost-effective and technically feasible" by carrying out impact assessments and cost-benefit analyses (CBA) prior to the introduction of any new measure (article 13/3).

At present, no formal MSFD-measures regarding underwater noise have been proposed, so formally an SCBA is not required. However, the overview of costs and benefits can be used to consider the conditions and measures to be included in permits for human activities in the Dutch Exclusive Economic Zone (EEZ). Rijkswaterstaat (RWS) has decided that at this stage there is added value in performing an SCBA, since this study can serve as a basis for the national transposition of the European Nature Conservation policies which include MSFD, Habitat and Birds Directive (Natura2000), the Water Framework Directive and the conservation plan for the Harbour Porpoise.

The issue of underwater noise and policy on noise mitigating or preventing measures is also particularly relevant in the context of the Energy Agreement for Sustainable Growth (EA). One important element of the EA is the objective of 4,450 MW installed offshore wind power in 2023, to be realised through a phased procurement procedure starting in 2015. Parties are also committed to a substantial reduction in costs of offshore wind projects. The need for insight into the influence of measures to mitigate or prevent underwater noise on the costs and timely completion of these projects is another purpose for this study.

This SCBA investigates (packages of) measures that may reduce underwater noise in three different activities, comparing their costs and benefits. The activities that are investigated include:

- Pile driving (for offshore wind farms)
- Seismic research
- Shipping.

The table below gives an overview of the characteristics of the baseline alternative and the policy alternatives for these activities.

Activity	Baseline alternative	Alternative 1	Alternative 2
Pile driving	*"Baseline alternative"* Pile driving restriction period in the North Sea (Dutch EEZ) from January 1st to July 1st Permit requirements: application of soft start and acoustic deterrent devices (ADD's)	*"No restriction period"* No seasonal restriction Permit requirements: application of soft start and ADD's Threshold sound level 160 dB re 1 μPa^{2}s (single strike SEL at 750 m)	N/A
Seismic research	*"Baseline alternative"* Permit requirements: application of soft start and acoustic deterrent devices (ADD's)	*"Procedural measures"* Procedural measures such as seasonal restrictions (January 1 to July 1) plus application of soft start and acoustic deterrent devices (ADD's)	*"Fewer surveys"* 50% fewer seismic surveys by reprocessing of data
Shipping	*"Baseline alternative"* No national (Dutch EEZ) restrictions or mandatory measures Recommendation to follow the international guidelines by IMO	*"Procedural measures"* Procedural measures: Speed reduction	*"Technical measures"* Reduction of 10 dB re 1 μPa^{2}s by taking technical measures, such as: Propeller design; Machinery isolation; Hull (romp) design and surface.

Table 0-1 Overview of baseline alternative and alternatives for all activities

As part of the SCBA method used, it was attempted to monetise as many effects as possible. Where this was not possible, a quantitative or qualitative assessment was performed instead. In this SCBA an important benefit of the alternative measures is the effect that the number of marine mammal disturbance days decreases compared to the baseline alternative, because additional mitigation measures are implemented. A marine mammal disturbance day is the product of the number of disturbed mammals (in this case harbour porpoises) per day of disturbance by piling (or seismic surveys) and the number of days during which the disturbance takes place (keeping in mind the difference in seasons and the duration of the disturbance per disturbance day). In this way, the benefits from reducing underwater noise can at least be quantified. For example, for pile driving a seasonal restriction (baseline alternative) causes more marine mammal disturbance days compared to the alternative of implementing a noise threshold with accompanying measures (alternative "no restriction period") according to TNO (2015). Monetisation of this effect however, is not yet possible as no valuation metrics exist.

The results of the analysis are presented in the tables below (one table per activity). The tables show the (qualitative, quantitative or monetary) values of the effects for a certain reference year during the time horizon. The monetary values in the tables refer to the value of effects in a certain reference year (please note, these values are expressed in real terms, not present values). For each activity, the net present value for costs and benefits has also been calculated, for the effects that could be monetised. It is important to note that only monetary values (expressed in EUR) may be added up per activity to calculate the total level of costs and benefits per year. However, it is not possible to calculate an overall figure per activity per year as not all effects could be monetised or even quantified.

Pile driving

Effect	Unit	"no restriction period"
Avoided non-workable days	EUR	15,000,000
Cost of noise mitigating measures	EUR	- 18,000,000 to -72,000,000
Avoided marine mammal disturbance days	Number	85,513
Avoided delayed start	EUR	1,575,000
Price decrease of cost price wind energy	%	0.7%
Impact on achieving tender program offshore wind farms	Qualitative	0/+

Table 0-2 Summary of effects in any reference year in the period 2016 – 2022, prices are in EUR, price level January 2015[1]

The net present value for costs and benefits has also been calculated, for the effects that could be monetised. However, as one of the most important effects (avoided marine mammal disturbance days) could not be monetised, the NPV is of limited value. For the alternative "no restriction period" of the activity pile driving, the NPV is between -/- EUR 8 million and -/- EUR 314 million (both +PM and depending on costs of noise mitigating measures).

From the table above, it can be derived that for the effects that can be monetised, the benefits do not outweigh the additional costs that are required to introduce sufficient measures. Even though the number of non-workable days and the probability of a delayed start have decreased, the costs of implementing the measures are very high.

In an additional analysis, the break-even point has been investigated. The break-even point between costs and benefits (the net present value must then be zero) lies at EUR 16.6 million (for two wind farms). This means that, if the implementation costs for the measures can be reduced to approximately EUR 8 million per wind farm, the NPV would be positive and the project would be socioeconomically viable. Since marine mammal disturbance days cannot be monetised, this result would improve even further if those could be monetised.

[1] Results based on 2 wind farms of 350MW each (see also paragraph 2.2.2.)

Seismic research

Effect	Unit	Alternative "Procedural measures"	Alternative "Fewer surveys"
Costs for implementing policy	EUR	0	0
Avoided marine mammal disturbance days	Number	+	++
Delay in executing surveys	EUR	- 12,600,000	0
Hitting dry wells	EUR	0	- 75,000,000

Table 0-3 Summary of effects in any reference year between 2015 and 2044, prices are in EUR, price level January 2015.

The net present value for costs and benefits has also been calculated, for the effects that could be monetised. However, as one of the most important effects (avoided marine mammal disturbance days) could not be monetised, the NPV is of limited value. For the alternative "Procedural measures" of the activity seismic research, the NPV is -/- EUR 190 million.

From the summarising table and the NPV calculation, it can be concluded that even though the measures in both alternatives do not bear immediate additional costs, the negative impact is very significant. In the alternative "Fewer surveys", reduced quality of research due to reprocessing of existing data results in more dry wells being hit, which leads to an NPV of over -/- EUR 1.1 billion over a period of 30 years.

However, the number of marine mammal disturbance days that is avoided due to the measures is also significant: even though it cannot be estimated at this stage the number of avoided days is positive in both alternatives.

Shipping

Effect	Unit	Alternative "Procedural measures"	Alternative "Technical measures"
Costs for implementing policy	EUR	0	PM
Avoided marine mammal disturbance days	Qualitative	+	++
Travel time and travel costs ships	Qualitative	-	+
Travel time goods	Qualitative	-	0
Emissions	Qualitative	+	+

Table 0-4 Summary of effects in any reference year between 2015 and 2039.

Unfortunately, very little is known about the benefits, costs, direct and indirect effects of measures for shipping. As a result, in this study it is not possible to quantify, let alone monetise, the relevant effects. In executing the study it was attempted to create a bandwidth around the results as a minimum, but this proved to be impossible, as the interviews with the activity representatives did not yield any relevant (quantified) information.

From the table, it can be derived that imposing a lower speed limit has both positive and negative effects, where the costs of implementing the policy would be close to zero. Marine mammal disturbance days as well as emissions are positively impacted, whereas the travel time and costs for both ships and goods will be impacted negatively. It cannot be established what the resulting effect is. It is suggested that this research is done for specific areas and/or specific fleets.

If technical measures are introduced, the expected positive effect on marine mammal disturbance days is greater, whereas the other effects are also impacted positively. Therefore, the net benefits are clearly positive. However, the costs of such operation are at the moment fully unknown. Considering the size and impact of the measures on fleets, it can only be estimated that the costs will be (very) high. It is strongly recommended that more research in this field is executed.

Recommendations

Recommendations that follow from this study are:

- For pile driving specifically, it would provide helpful insights if more information would be available about the costs of individual measures rather than an overall estimate of packages, as this would enable the comparison for these measures in terms of cost-effectiveness (in other words, the costs must be determined project-specifically) . Moreover, if the costs for the measures can be decreased to EUR 8 million per wind farm, the (social) benefits would outweigh the costs. It is noted that a ‘one fits all’ solution to reduce the effects arising from pile driving does not exist. A project specific package needs to be investigated for each situation. Due to the increased use of packages of measures, economic theory implies that significant cost reductions may be possible (increased use of measures reduces the costs of producing such measures).
- As explained in this report, the measures for the shipping sector cannot be monetised yet (the costs are yet unknown; no useful data could be derived from the interviews), it is advised that this topic is researched further. Also, a separate CBA for specific measures and specific fleets would be useful, as quantified and, where possible monetised, results can be gathered to bring focus to the discussion.
- ‘Marine mammal disturbance days’ is used as an index number for the measurement of ecological effects in this SCBA. However, at present this index cannot be monetised, which makes comparison between alternatives and between effects difficult. We recommend that research is done how to value this aspect.
- Several studies on effects of underwater noise are ongoing, particularly on the effects of impulsive noise (generated by pile driving and seismic surveys) on marine mammals. Ambient noise, produced by shipping for example, can also have an effect on marine animals. Shipping is an increasing activity which contributes significantly to increasing background underwater noise. More studies on effects of ambient sound on marine life in the North Sea should be performed to get a better indication of effects on marine life. When this information becomes available, a better estimation of social costs and benefits of mitigating measures and ecological effects can be made and an update of this SCBA is recommended.

- Little is known about the effects of underwater noise on other marine animals besides marine mammals. Also effects on marine ecosystem level are scarce. Therefore, this study only focuses on the effects of underwater noise on marine mammals, and specifically on the harbour porpoise. However, reducing underwater noise could also have an effect on other marine animals such as birds, fish, turtles etc. and the marine environment. It is advised that this is researched further.

It is the view of the authors of this report that the findings from this study are useful for several purposes. First of all, the fact finding activities that were undertaken form an important part of the project, which results in bringing together data on costs of measures to prevent and mitigate underwater noise. This type of data had not been collected and presented in this way before. At the same time, this is also a first step to compare the cost effectiveness of measures aimed at different activities (i.e. pile driving, seismic surveys and shipping), even when the costs for individual measures could not be estimated. The second contribution of these findings lies in the monetised values of at least a part of the effects. Whereas one of the main goals of any measure, decreasing marine mammal disturbance, cannot currently be monetised, at least part of the costs and benefits could be monetised, making the outcomes comparable. This means that when in the future marine mammal disturbance days can be monetised as a result of further research, a full comparison on SCBA level will be possible (it is suggested that an SCBA on project level is executed). But even when not considering the ecological benefits, a main finding is that bringing the costs of measures down to a level calculated in this study (approximately EUR 8 million per wind farm), means that on a purely monetary basis alone, the benefits equal the costs of mitigating measures (compared to the restriction period). It is advised to investigate whether location specific packages of measures under EUR 8 million are feasible for wind farms.

CONTENTS

1 INTRODUCTION

1.1 Project description

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At present, no formal MSFD-measures regarding underwater noise have been proposed, so formally an SCBA is not required. However, the overview of costs and benefits can be used to consider the conditions and measures to be included in permits for human activities in the Dutch Exclusive Economic Zone (EEZ). Therefore, Rijkswaterstaat (RWS) has decided that at this stage there is added value in performing an SCBA, since this study can serve as a basis for the national transposition of the European Nature Conservation policies which include MSFD, Habitat and Birds Directive (Natura2000), the Water Framework Directive and the conservation plan for the Harbour Porpoise (Camphuysen & Siemensma, 2011).

The issue of underwater noise and policy on noise mitigating or preventing measures is also particularly relevant in the context of the Energy Agreement for Sustainable Growth (EA). In this Agreement, over forty stakeholders jointly laid down targets for energy savings and renewable energy in The Netherlands. One important element of the EA is the objective of 4,450 MW installed offshore wind power in 2023, to be realised through a phased procurement procedure starting in 2015. Parties are also committed to a substantial reduction in costs of offshore wind projects. The need for insight into the influence of measures to mitigate or prevent underwater noise on the costs and timely completion of these projects is another purpose for this study.

1.2 Problem analysis

This section describes the problem analysis of the study. In general, the SCBA investigates (packages of) measures that will reduce underwater noise resulting from three different activities, and compares their costs and benefits to the baseline alternative.

1.2.1 Ecological relevance of reducing underwater noise

This section aims to give a short introduction and background on the ecological importance of underwater noise, and the question why underwater noise is an issue that needs to be regulated. For this SCBA, the currently available knowledge on the effects of underwater noise on marine species is used and described in general. Also, it is discussed why reducing levels of underwater noise is important. Underwater noise is a complicated science. To make the text easier to read, aspects of underwater noise are being presented in a simplified way. For details we refer to the literature. This chapter explains which sources of noise are important to regulate and why.

Relevance of underwater noise

Studies have shown that underwater noise can adversely affect marine species (Richardson et al, 1995; Kastelein et al, 2008). Several experts have researched the effect of (underwater) noise on individual harbour porpoises, i.e. Lucke et al (2008); Kastelein, 2013 and 2014; Diederichs et al., 2014; Dähne et al., 2013 and Thompson et al. 2013. Also during field studies, avoidance of marine mammals has been observed e.g. during construction of wind farms (Diederichs et al., 2014; Dähne et al., 2013 and Thompson et al. 2013). The observed effects on individual animals may have an effect on the population in the North Sea. For example, underwater noise can have an effect on the individual's ability to forage. This in turn may impact the survival rate or the reproductive success because the vitality of the individual animal may be impaired. It can also possibly lead to a change in behaviour which can have an effect on the survival rate i.e., when a mother and calf would be separated (Miller et al. 2012; TNO 2015). Studies have proven that underwater noise has an effect on the individual level of marine species. However the extent of these effects on the population of for example harbour porpoises and other marine species is still under research.

In 2008 the European commission has added energy, including underwater noise, as a descriptor for a Good Environmental Status (GES) in the Marine Strategy Framework Directive (MSFD) (EU, 2008). The MSFD states that for a Good Environmental Status "introduction of energy, including underwater noise, is at such levels that they do not adversely affect the marine environment" (EU, 2008). In 2010 the European Commission decided on indicators that need to be used by Member States to describe GES (EU, 2010).

The Commission Decision of 2010 distinguishes between two categories of noise: (1) short duration noise or **impulsive noise** (e.g. impulsive such as from *seismic surveys* and *pile driving for wind farms* and platforms, as well as explosions) and (2) continuous or **ambient noise** (such as dredging, *shipping* and energy installations) affecting organisms in different ways. For the implementation process of the MSFD in the Netherlands see Appendix K.

Improved descriptions of the indicators have been provided in the Monitoring Guidance provided by the EU expert group TG Noise (Dekeling et al., 2014)

Loud, low and mid frequency impulsive sounds (indicator 11.1)

1. The proportion of days and their distribution within a calendar year, over geographical locations whose shape and area are to be determined, and their spatial distribution in which source level or suitable proxy of anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceeds a value that is likely to entail significant impact on marine animals.. Most relevant activities that produce impulsive noise are e.g. pile driving and airguns used for seismic surveys.

Ambient low frequency sound (indicator 11.2).

2. Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate. The most common noise in the Dutch EEZ is from shipping and this leads to higher background levels.

Noise sources

Underwater sound behaves very differently compared to sound in the air as sound travels faster in water than in air (~1500 m/s vs. ~340 m/s) (Dol & Ainslie, 2012). Noise is perceived more intensely underwater and can propagate over greater distances. However, the distance travelled by and the intensity of noise underwater are also dependent on i.e. water depth and soil conditions. In general, in deeper water sound is transmitted further than in shallow areas.

Hildebrand (2009) described that noise in the ocean is the result of both natural and anthropogenic sources. Natural sources of noise include processes such as earthquakes, wind-driven waves, rainfall, bio-acoustic sound generation, and thermal agitation of the seawater. Anthropogenic noise is generated by a variety of activities, including commercial shipping; oil and gas exploration, development, and production (e.g. air-guns, ships, oil drilling); naval operations (e.g. military sonars, communications, and explosions); fishing (e.g. commercial/civilian sonars, acoustic deterrent, and harassment devices); research (e.g. air-guns, sonars, telemetry, communication, and navigation); and other activities such as construction, icebreaking, and recreational boating. Noise produced by human offshore activities varies in frequency range, intensity and duration. In this study, we focus on the activities that are known to produce the highest amount of acoustic energy. Ainslie et al. (2009) showed that the most important sources of anthropogenic noise in the North Sea are **airgun arrays, shipping and construction of wind farms (pile driving) and explosions**. This study focuses on seismic surveys, piling and shipping; the need to take additional measures for explosions is being investigated by the Ministry of Defence.

In the next chapters the effects and costs / benefits of measures to mitigate or prevent underwater noise are described per activity; offshore pile driving, seismic surveying, and shipping respectively. Each activity is a source of low frequency noise. However, pile driving and seismic research produce impulsive sounds, while shipping produces a long lasting ambient sound. The way noise can be perceived is dependent on many different factors including location, depth, soil type, weather conditions (wind and waves), etc.

1.2.2 Scoping Ecological effects

More details on the available information of the underwater noise effects on marine species is included in Appendix A. Below only the essential parts for this SCBA are presented.

As described above, there are different types of underwater noise. But, there is also a great diversity in hearing and in the biological effects of noise among marine species (Southall et al., 2007). Van der Graaf (2012) has divided the effects of underwater noise on marine mammals according to sound pressure and frequency in different categories: hearing zone, reaction in behaviour, masking (when anthropogenic noise interferes with the sounds produced by animals), hearing damage and other physical or physiological damage or even death. Hearing damage can be divided in two categories: temporary threshold shift (TTS) when temporary hearing damage occurs or permanent threshold shift (PTS) when permanent hearing damage occurs. Effects with consequences for disturbance, damage and masking can have influence on individual levels, but also on population levels. The ecological effects are different depending on the type of noise produced; impulsive sound has another influence on marine species than low frequency ambient sound.

Impulsive sound

Current knowledge suggests that the harbour porpoise is the most vulnerable species to noise pollution as a result of impulsive sound in the Dutch EEZ (due to pile driving and seismic surveys) and is mostly affected by this type of underwater noise. Since the harbour porpoise's hearing is more sensitive than that of seals (harbour seal and grey seal) (Lucke et al., 2010, Kastelein et al., 2011, TNO 2015), it was chosen to focus on the impact of regulations on the harbour porpoise disturbance as a worst case scenario for impulsive sound (pile driving and seismic surveys). It is assumed that when regulations and accompanying mitigation measures for pile driving have a positive effect on harbour porpoises, this will at the same time reduce the impact of pile driving on harbour seals, grey seals and other marine mammals such as whales and dolphins, but also on other marine species such as fish (and their larvae and eggs). In this report, the effect of underwater noise on whales and dolphins will not be described, which does not mean that there are no effects of underwater noise on these marine mammals, nor that mitigation is not needed. In future projects, effects of underwater noise on all marine animals will have to be described in Environmental Impact Assessments (EIA) or Appropriate Assessments (AA) or permit applications. The use of a soft start and an Acoustic Deterrent Device (ADD) deters the marine animals preventing permanent damage as a consequence of impulsive noise.

For specific information on type of effects on marine animals, see Appendix A.

There is some information on effects on marine individuals, but very few studies are done yet that show results on effects on population levels. TNO (2015) has done a study on cumulative effects of underwater noise. In this study harbour porpoise disturbance days were calculated (see for explanation 5.1.3). The study shows that by implementing a 160 dB re 1 $\mu Pa^2 s$ Sound Exposure Level (SEL) at 750 m threshold level, as implemented in Germany, the number of harbour porpoise disturbance days decreases significantly. The study has also related the decrease of disturbance days to effects on population levels. The model showed that when the German threshold level for underwater noise is implemented, effects on the population level (harbour porpoise) are small and do not exceed the natural variation of the population development. Therefore, it is considered as an effective measure. In the following chapters, the alternative for pile driving will therefore contain the German threshold level.

Ambient sound

Low frequency ambient sound has another influence on marine species than impulsive sound. Little information and certainly no quantitative data are available on ecological effects of ambient sound on marine species. The Marine Board (2008) has urged to set up research programs to investigate the effects of shipping on marine mammals. It is expected that fish are sensitive for this type of sound as they use low frequencies for communication. When background noise increases, mainly due to shipping, this can affect the communication (masking) of fish, predator-prey relationships and possibly even population levels (Slabbekoorn et al., 2010). Not only fish are affected, marine mammals also have shown effects; masking, changes in behaviour and habitat displacement are effects that are mentioned as most urgent for marine mammals concerning shipping (OSPAR, 2009).

Harbour porpoise disturbance days have only been calculated for impulsive sound (pile driving and seismic surveys) and not for ambient sound since the effects of ambient sound are not well researched yet. However harbour porpoise disturbance days have been used as an indicator for shipping in this SCBA because of lack of better information

Cause-effect relationships
Despite ongoing research and monitoring programs to increase insight into ecological effects, it is still difficult to determine effects of underwater noise due to impulsive and ambient sound at the population or even ecosystem level. In this report the most recent information is used, but more knowledge is needed. The current mitigation measures are based on research that has been done on the effects of impulsive sound on individual animals, while effects on population levels are still little researched. Therefore, it is difficult to quantify and study the cumulative effects of underwater noise. There are several international research programs aiming to acquire a better understanding, and in the near future more data will be available. Cumulative effects are not addressed in this study.

1.2.3 Underwater noise produced by pile driving

Pile driving is a technique to install piles for i.e. offshore wind farms that produces a strong impulsive underwater noise. The percussive pile driving for offshore installations is one of the stronger sources of underwater noise (Madsen *et al.*, 2006 in Ainslie et al. 2009). Commonly a hammer is used to drive the pile into the seabed for stability, but other techniques are possible (see Appendix D and E). This chapter focuses on pile driving. The variables for constructing a wind farm are large: piling techniques, pile sizes, pile types, depth at the location, seabed conditions, weather conditions, etc. These variables determine e.g. the time needed for pile driving (and thus the length of disturbance), but also underwater noise produced by pile driving.
Ainslie et al. (2009) described the acoustic energy of pile driving. The figure below compares several studies of offshore wind farms at different depths (and one harbour construction). As shown in the figure below, the spectra at different frequencies vary depending on the wind farm. This means that every pile driving activity is unique, has its own underwater noise characteristics, and affecting marine life in a specific way.

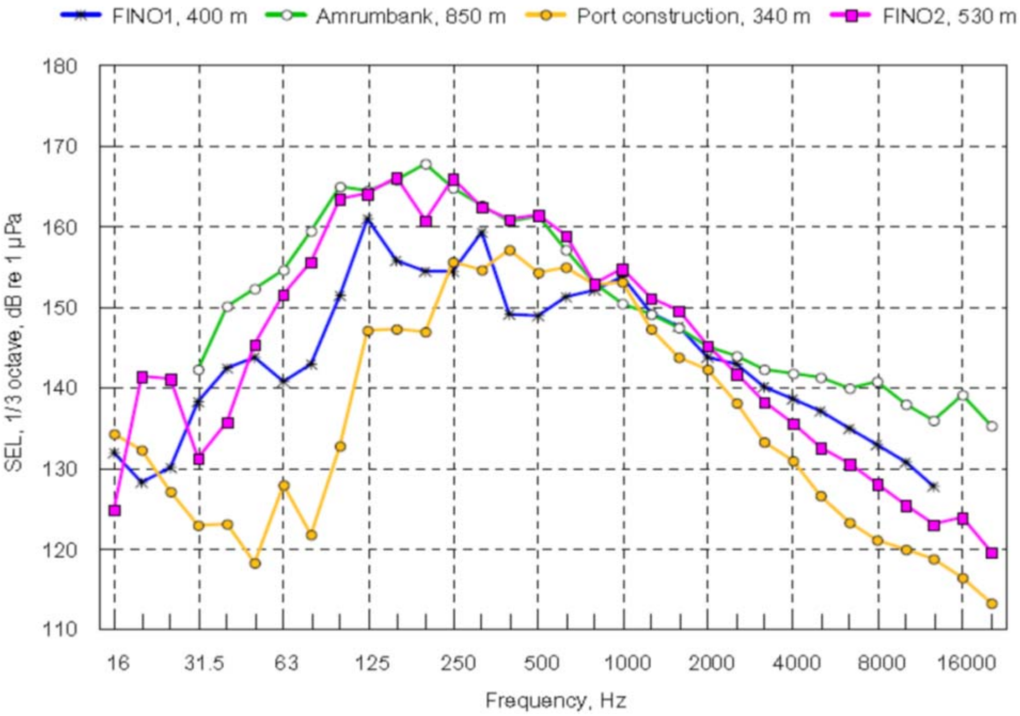


Figure 1: Overview of Third-Octave band spectra of the single stroke SEL of some of the monopile driving operations from different wind farm, data from Nehls et al. (2007) in Ainslie et al. (2009). (Figure from Ainslie et al., 2009).

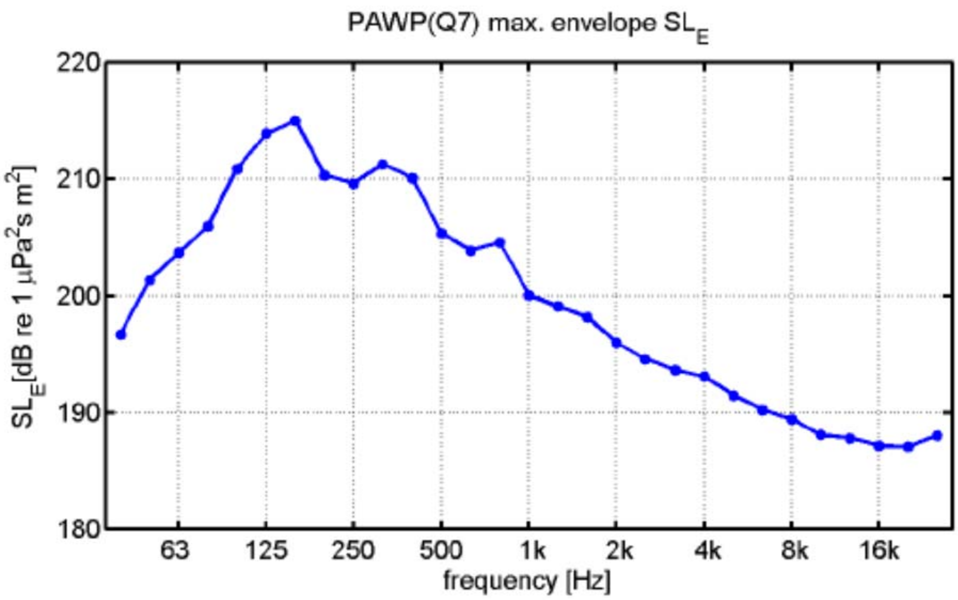


Figure 2: Estimated upper limit of the energy source spectrum (1/3 octave) for underwater noise while pile driving based on measurements during the building of the wind farm Prinses Amalia (Q7). Figure from TNO, 2015.

In the figure above the spectrum of the energy source (1/3 octave) for underwater noise while pile driving based on measurements during the building of the wind farm Prinses Amalia at the Dutch coast is shown. This park used monopiles of 4 meter in diameter. It is expected that the construction of future wind farms will generate higher energy levels as larger piles will be used.

Various studies have suggested different noise thresholds for marine mammals (Heinis, 2013). In TNO (2015) the most recent information is used and the calculated distribution of SEL_1 (noise perceived by animal during a single strike) and SEL_{cum} (cumulative noise or noise perceived by an animal when hammering one complete pile) are modelled for the construction of a wind farm. From the data, PTS and TTS for harbour porpoises could be deducted at 0,5 km and 16 km respectively for a specific wind farm (TNO, 2015). These results are calculated for a specific situation and are not generally applicable. Before constructing a wind farm, specific calculations on underwater noise and the description of effects on marine life are made in an EIA.

The working group underwater noise has agreed that the most significant effect of underwater noise is PTS and avoidance. PTS must be avoided through mitigation by applying a soft start and a acoustic deterrent device (ADD). Thus, avoidance becomes the most important effect that occurs from increased levels of underwater noise. Therefore the harbour porpoise disturbance days are based on avoidance threshold levels. See table below for the threshold values that are used to determine the effects of impulsive sound on harbour porpoises and harbour seal (TNO, 2015).

Species	Type of effect	Threshold value	Literature
Harbour porpoise	Avoidance	SEL_1 > 140 dB re 1 μPa^2s/ 136 dB re 1 μPa^2s	TNO (in 2015) / Kastelein et al. 2011
	TTS-onset	SEL_{cum} > 164 dB re 1 μPa^2s	Lucke et al. 2009
	TTS-1 hour	SEL_{cum} > 169 dB re 1 μPa^2s	TTS-onset + 5 dB
	PTS-onset	SEL_{cum} > 179 dB re 1 μPa^2s	TTS-onset + 15 dB
Harbour seal	Avoidance	$SEL_{1,w}$ > 145 dB re 1 μPa^2s	Kastelein et al. 2011
	TTS-onset	$SEL_{cum,w}$ > 171 dB re 1 μPa^2s	PTS-onset – 15 dB
	TTS-1 hour	$SEL_{cum,w}$ > 176 dB re 1 μPa^2s	TTS-onset + 5 dB
	PTS-onset	$SEL_{cum,w}$ > 186 dB re 1 μPa^2s	Southall et al. 2007

Table 1: Calculated threshold values that have a certain impact on harbour porpoises and harbour seals. Sound exposure level (SEL) is proportional to the total energy of a signal expressed in dB re 1 μPa^2s. Source Southall, 2007. SEL_1 = noise level of one single strike; SEL_{cum} = noise level perceived by a marine mammal after pile driving activity of one pile thus multiple strikes; $SEL_{1\ +\ cum,w}$ = M-weighted SEL for seals in water, see Southall, 2007 (see also TNO, 2015).

Effects of impulsive sound generated by pile driving on marine life can be substantial. If no measures are taken, PTS or even death of marine mammals can occur (see 1.2.2). Therefore a soft start and an ADD are used to deter the marine mammals and fish and permanent damage is avoided. A soft start for pile driving is the use of a hammer at lower power (in kJ) during the first 30 minutes, which is part of the regular pile driving procedure for each monopile. This start up is especially used to stabilize the heavy weighted hammer on the sea bottom, but is also as a good deterrent measure for marine mammals.

For specific ecological effects of pile driving see Appendix A.

1.2.4 Underwater noise produced by seismic research

Seismic research is part of the process for exploration and production of oil and gas. There are three different types of methods to conduct seismic research: 2D, 3D and 4D seismic surveys (see text box below). The Dutch Continental Shelf has been almost completely covered by seismic research, however 'reshooting' of the area is important to acquire better data on small or changed oil and gas fields. The purpose of seismic research is to map the geological characteristic of the earth layers and to receive accurate data to minimize the chance of drilling a "dry well". Commercial seismic surveys are conducted using airguns[2] (CSA OCEAN SCIENCES INC., 2014; OGP, 2011) that produce a powerful impulsive noise.

Different types of seismic surveys

2D seismic research
Most of the Dutch continental shelf has already been covered by 2D seismic surveys. 2D seismic research is done using one boat with one line of streamers and a set of airguns attached to it. As only one line is used to acquire data the survey ship needs more time and must sail more lines to cover a certain area.

3D seismic research
Nowadays 3D seismic surveys are a more conventional method to conduct seismic research. 3D seismic surveys works according to the same principle as 2D seismic research but uses more lines, streamers and airguns. With more airguns the survey time can be decreased as a larger area is covered faster.

4D seismic research
4D seismic research is also known as time-lapse surveys and hence the data density is higher over the same area, over a period of time because there are multiple data points over the same location (OGP, 2011). The technique is no different than 3D seismic research. It gives the operations insight in the storages of oil and gas in time.

An airgun is a relatively simple mechanical device that stores compressed air in a reservoir and releases it rapidly through small ports when a firing command is received. When an airgun shoots, part of the energy contained in the escaping compressed air is

[2] The average cost of a seismic survey is 20 million euro.

converted to sound, thereby generating a seismic signal that travels into the earth's subsurface (Dragoset, 2000). It creates an oscillating air bubble in water. The expansion and oscillation of this air bubble generates a strongly peaked, high amplitude acoustic impulse that is useful for seismic profiling (CSA Ocean Sciences Inc., 2014). The noise produced through airguns is essential to conduct seismic research. Airguns can differ in type (broadband/ singleband source), size (volume) and capacity. In general, the air pressure is around 2,000 psi (Dragoset, 2000, CSA Ocean Sciences Inc. 2014) and the guns are deployed around 3 to 10 meters below the water surface. During seismic surveys an array of multiple airguns is used, giving a signal every 8 seconds. The airguns generally produce low frequency noise which is needed to conduct seismic profiling. In addition, airguns emit 'wasted' sound at frequencies above 100 Hz.

The noise produced by the airguns depends mostly on the array (or configuration of lines and positioning of the airguns) and the number of airguns used. The volume and type of the airguns and the depth also play a role for underwater noise production. All these factors influence each other and when one of the factors is being changed, it is difficult to describe the change in underwater noise produced. For each set of airguns a separate calculation should be made. The effects of airgun volume and type on marine life alone are unknown and it is not certain that larger airguns (incl. volumes) have greater effects on marine life compared to smaller airguns (personal comment M. Ainslie).

There are several methods to perform seismic surveys: conventional marine data acquisition or continuous line acquisition (CLA). CLA is an innovative procedural method which can reduce the time of the survey and minimize the area which the survey ship has to cover. During CLA the seismic vessel doesn't sail along parallel lines but in a semi-circular pattern (see figure below).

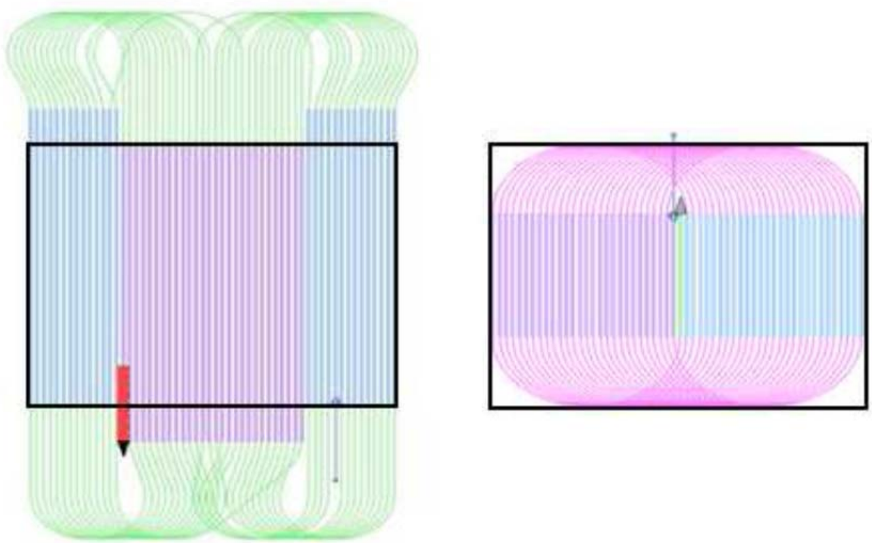


Figure 3

The left image shows the progress of a conventional marine data acquisition project, the right image shows the Continuous Line Acquisition method (note the full-fold areas are equivalent).

According to Ainslie et al. (2009), seismic research is one of the most important producers of underwater noise. The total frequency bandwidth of an airgun lies between the 0 and 10,000Hz, but the intensity of noise levels decreases significantly above a frequency of 500 Hz. TNO has modulated a single shot broadband spectrum of a 50.6 l airgun (see figure below). The noise level is expressed as an average of a certain frequency with a bandwidth of 1/3 octave. The maximum noise level of this modelled standard airgun is reached at a frequency of 150 Hz. Noise levels decrease significantly at frequencies above 500 Hz. The figure (right) shows the simulated decrease in the broadband signal (SEL) produced by the airgun at different distances from the source for three different depths.

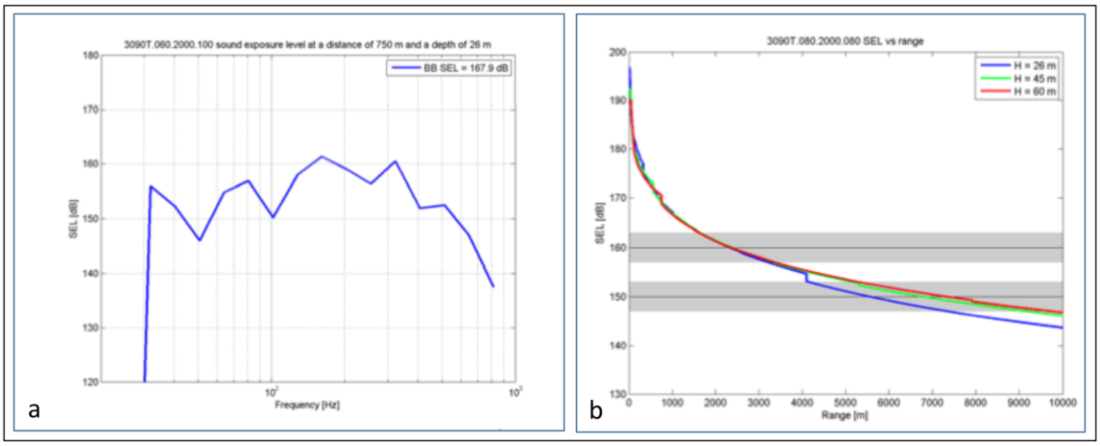


Figure 4

TNO airgun modulation. Modelled noise levels of one strike at a distance of the source (SEL, dB re 1 μPa²s) of a 50.6L airgun shown at three different depths (TNO, 2011).

In the TNO modulation (TNO, 2011), the calculated SEL at 750 meter distance was between 168 dB re 1 μPa^{2}s and 173 dB re 1 μPa^{2}s, depending on the array configuration. The model predicts that the SEL will fall below 160 dB re 1 μPa^{2}s (SEL at 750 m) at a distance between 1.5 km and 3 km from the source, in a water depth of 26 meter, when using an airgun of 50.6 L with the array noted in TNO (2011).

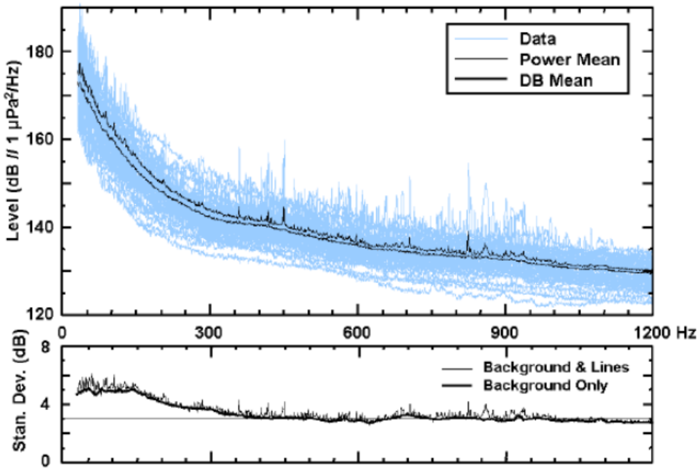
Not for all airguns (types and sizes), model calculations are available and therefore the best available techniques and a combination of different information sources (like calculations for piling) are used nowadays to estimate effects of airguns on marine mammals (TNO 2011, TNO 2015). The difference between pile driving and airguns is particularly notable when it comes to the cumulative impulsive noise levels (SEL_{cum}), which is important for calculations of TTS and PTS. The TTS decreases when the silent interval periods between the impulsive noises are longer (Kastelein et al, 2014). To avoid PTS, a soft start procedure is applied. This means that the airgun pressure is slowly ramped up to full capacity over a period of 30 minutes. Additionally an ADD is used to deter animals. This makes avoidance the ecologically most important effect.

1.2.5 Underwater noise produced by shipping

Oceans provide an important means of transportation. Commercial shipping has been increasing during the last decades, not only in the number of ships to support global trade (global and port to port transport), but also in ship size, power, and sophistication (cruises, etc.). This results in an increase in underwater acoustic output generated by commercial ships. This contributes to ambient noise in the ocean (authors in McKenna et al., 2012). It is estimated that there has been an approximate doubling (3 dB increase) of background noise per decade since 1950s in some ocean areas, where sufficient measurements support such analysis (OSPAR, 2009). Commercial shipping is the most probable source of that increase.

Underwater noise from commercial ships is produced mainly from propeller cavitation. The underwater noise generated by ships is known to peak at 50 – 150 Hz but can extend up to 10,000 Hz caused by on-board machinery, hydrodynamic noise from the flow around the ship hull and appendages. Also operational modification issues are relevant. In addition incidental activities, such as anchoring or on board hammering, may cause underwater noise. The noise depends on a wide range of parameters, such as the ship design, the current state of maintenance, the operational settings (the selection of operational machines and their speed setting) and environmental conditions such as wave height and direction (Ainslie et al., 2009). At low speeds, it is possible to avoid cavitation, however at high speeds cavitation will occur with underwater noise as a result.

Little is known about the background noise generated by shipping. Therefore a European project (SONIC) has been set up to investigate the noise production of different types of ships and their contribution to the background noise. The SONIC project aims to develop tools to investigate and mitigate the effects of underwater noise generated by shipping (http://www.sonic-project.eu/), and will be finished in October 2015. Measurements in the field, with a lot of traffic, show that background levels of underwater noise are up to 100-120 dB re 1 $\mu Pa^2 s$ (with a frequency range of 10-10,000 Hz) (pers. comm. IHC Hammer).
Some data on underwater noise due to shipping is available from literature. This information is described below.



. Measured underwater noise source spectra of merchant ships (blue curves) and the ensemble average spectra (black curves: 'Power mean' refers to the energetic average, while 'DB mean' presents the average of the dB-values), with an estimation of the ensemble standard deviation (lower figure), from Wales & Heitmeyer (2002).

Figure 5: Measured under water noise spectra of merchant ships (picture from Ainslie et al., 2009).

There is a large difference in the noise propagated by the noisiest and the quietest conventional merchant ships (apart from the ships designed for low noise such as cruise ships) and noise production depends on several factors (numbers in table below). The speed of the vessel also has a direct relation to the production of underwater noise.

			Source spectral density (dB re 1 μPa^{2}m^2/Hz)				
Ship type	**Length (m)**	**Speed (m/s)**	**10 Hz**	**25 Hz**	**50 Hz**	**100 Hz**	**300 Hz**
Super tanker	244 – 366	7.7 – 11.3	185	189	185	175	157
Large tanker	153 – 214	7.7 – 9.3	175	179	176	166	149
Tanker	122 – 153	6.2 – 8.2	167	171	169	159	143
Merchant	84 – 122	5.1 – 7.7	161	165	163	154	137
Fishing	15 – 46	3.6 – 5.1	139	143	141	132	117

Table 2: Overview of source spectral densities for commercial vessels. (Source: Ainslie et al. 2009).

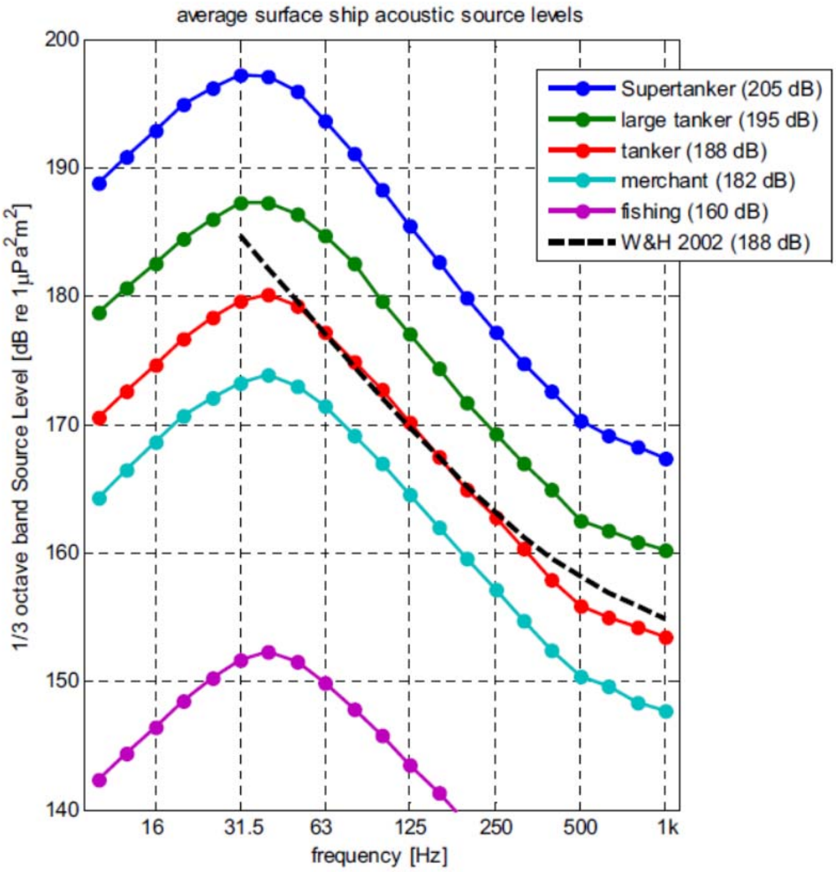


Figure 6: Comparison of source levels from merchant ships (average) (source: Ainslie et al., 2009). W&H 2002 stands for Wales & Heitmeyer (2002), who made an estimation of the ensemble standard deviation.

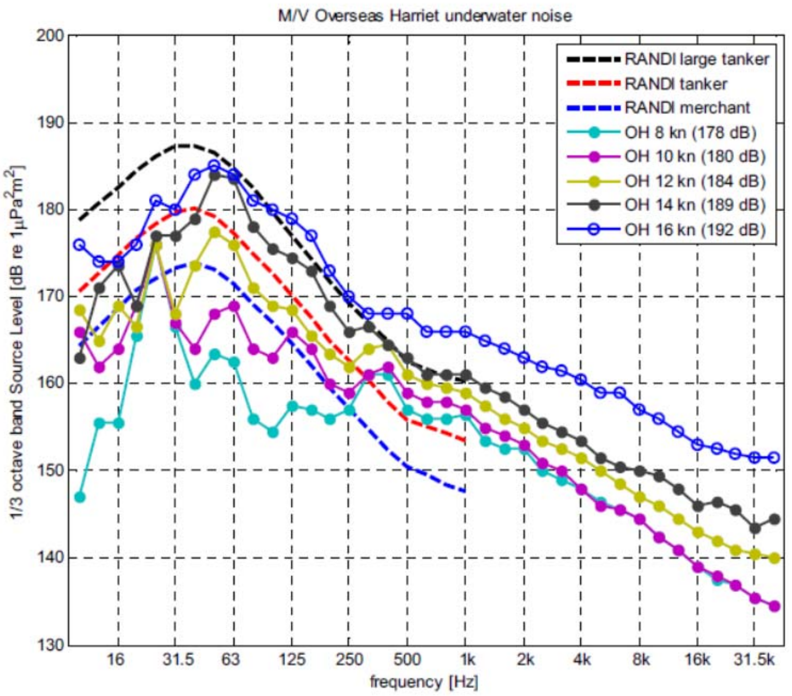


Figure 7: Relation between the reduction of speed and the production of underwater noise for the overseas Hariette (picture from Ainslie et al., 2009).

Studies show that background noise from a huge storm is comparable to that of background noise from shipping (Cato, 2008). The highest peaks of noise produced by ships occur in the lower frequencies and levels decrease at higher frequencies.
The Dutch North Sea is one of the busiest areas in the world in terms of ship traffic (www.marinetraffic.com). The underwater noise will mainly concentrate in and around shipping lanes, but individual ships (and their surroundings) can be an important source of underwater noise in certain quiet areas. Until now, no calculations are available on distances at which effects on marine animals occur.

1.3 Goal of SCBA

Government intervention needs to meet certain requirements, such as legitimacy, effectiveness and efficiency. The SCBA is primarily aimed at determining the efficiency of such interventions, but can also assist in assessing other criteria for government intervention. The SCBA enables the decision-making process around new or altered government policies. The SCBA does this by assessing whether the results of the intervention solves problems or perhaps even worsens them, and therefore, provides insight into whether intervention is economically legitimate. Measuring effects, which is necessary in order to determine the intervention's welfare effects, provides insight to determine whether the intervention is effective.

Decision-makers will benefit from a SCBA that matches the problem analysis and has support among stakeholders. However, the SCBA is often experienced as a black box, which is not conducive to her role. Therefore, it is important to clearly set out the process that is followed when conducting a SCBA as well as to report on the outcomes of each step in that process.

1.4 SCBA process

The table below describes the steps that are followed in conducting a SCBA. The problem analysis is an important first step as it sets out the government intervention that is being researched. This has been described earlier in this chapter as this SCBA has a peculiar setup, due to the fact that three different activities are being investigated.

Research steps of Cost Benefit analysis	
Problem Analysis	What problem or opportunity arises and how does it develop? What policy results from it? Which solutions have potential?
Determine the baseline alternative	Most probable development without policy Effect = policy alternative minus baseline alternative
Define policy alternatives	Describe the measures to be taken Unravel packages into their constituent parts Define multiple alternatives and variants
Determine effects	Identify effects Quantify effects Value (monetise) effects
Determine costs	Deployed resources to implement the solution Costs may be one-time or periodic, fixed or variable Only the extra cost compared to the baseline alternative
Draft overview of costs and benefits	Count all costs and benefits to the same base year and determine the balance Provide an overview of all effects including non-quantifiable and non-monetisable effects
Present results	Relevant, accessible and clear Accountability: transparency and reproducibility Interpret: What does the decision maker learn from the SCBA?

Table 3: Overview of the steps in the SCBA process, CPB / PBL (2013)

The next step will be to determine the baseline alternatives and project alternatives. In a SCBA, the effects of project alternatives are always compared to a situation in which the intervention would not take place. In doing so a clear picture of the economic effects of the intervention is obtained.

Following the determination of alternatives, the effects (costs and benefits) of the intervention are determined. Here, it is important to make a distinction between physical effects and welfare effects. Only the latter are included in the SCBA. This will be explained further in chapter 4. Moreover, a further distinction can be made between direct and indirect effects, which will also be elaborated on in chapter 4. There, also the general assumptions and principles regarding this SCBA will be explained.

Next, all relevant effects will be assessed and where possible, quantified and/or monetised. In cases in which this is not possible, a qualitative approach will be followed. A total overview of all effects (costs and benefits) is presented next, according to the usual method for presenting SCBA results in the Netherlands. From these overviews, conclusions will be drawn for all activities.

1.4.1 Interviews

This SCBA is performed using proven, currently applied, measures and innovative measures that have not been applied yet, but are expected to have a feasible application within the respective time horizons of the activities. This study has taken place both by review of literature and interviews with many stakeholders for each activity (see table below).

Interviews have been structured along a questionnaire which had been sent beforehand. Questions differ based on the role the interviewee has towards measures. The interviewees have reviewed the reports of their interview. The results of the interviews have been used in this report. A list of all interviewees is available in appendix H.

Role related to measures	Shipping	Pile driving	Seismic
Expert	Marin, BSH (Bundesamt fur Seeschiffahrt und Hydrographie)	JNCC, Bundesamt fur Natruschutz (BfN), Carbon Trust	JNCC
Offtaker (user)	-	Gemini, DONG Energy, Eneco, Van Oord	Hansa Hydrocarbons, Wintershall
Supplier	-	IHC Hydrohammer	-

Table 4: Stakeholders interviewed and interview report available for RWS, per category.

Furthermore RHDHV was present at the workshop organised by TKI Wind op Zee on November 12, 2014, about the regulation and mitigation of underwater noise caused by pile driving.

1.5 Reporting structure

This study has been conducted in two steps as much research was needed that would support the SCBA, but not be part of it according to the economic principles underlying the SCBA. For example, there are many physical effects that must be measured and researched to be able to make meaningful statements about welfare effects, but very often, the physical effects are not welfare effects themselves, and will therefore not be included in the SCBA. Such background information is included in the appendices of this report.

Chapter 2 contains the description of alternatives, chapter 3 contains the economic assumptions and principles. Chapter 4 contains the discussion and measurement of effects, while chapter 5 contains the conclusion of the study.

2 ALTERNATIVES

2.1 Baseline alternative

The next sections describe relevant policies for each sector that are part of the baseline alternative for each sector.

On the Dutch territories several Dutch laws are implemented. In the figure below, an overview of the current Dutch laws is given and specified for inland waters and land ("land en binnenwateren"), territorial sea and the Exclusive Economic Zone (EEZ). For the EEZ and in the context of this project all laws are relevant, but especially: shipping traffic law ("Svw[3]"), law concerning installations ("Win[4]"), law on environmental management ("wet milieubeheer"), nature conservation law ("Ffw[5]" and "Nbw[6]"), and Mining law ("Mbw[7]"). Not included in the figure below is the law on offshore wind ("Wet windenergie op zee"), which will be in force for the territorial sea and the EEZ. The bill has been passed by the Dutch House of Representatives and is currently awaiting approval by the Senate. The minister of Economic Affairs, in agreement with the minister of Infrastructure and the Environment, will become the responsible authority for the law on offshore wind.

[3] SVw: Scheepvaartwet

[4] Win : Mijnbouwwet

[5] Ffw: Flora- en faunawet.

[6] NBw: Natuurbeschermingswet 1998.

[7] Mbw: Mijnbouwwet

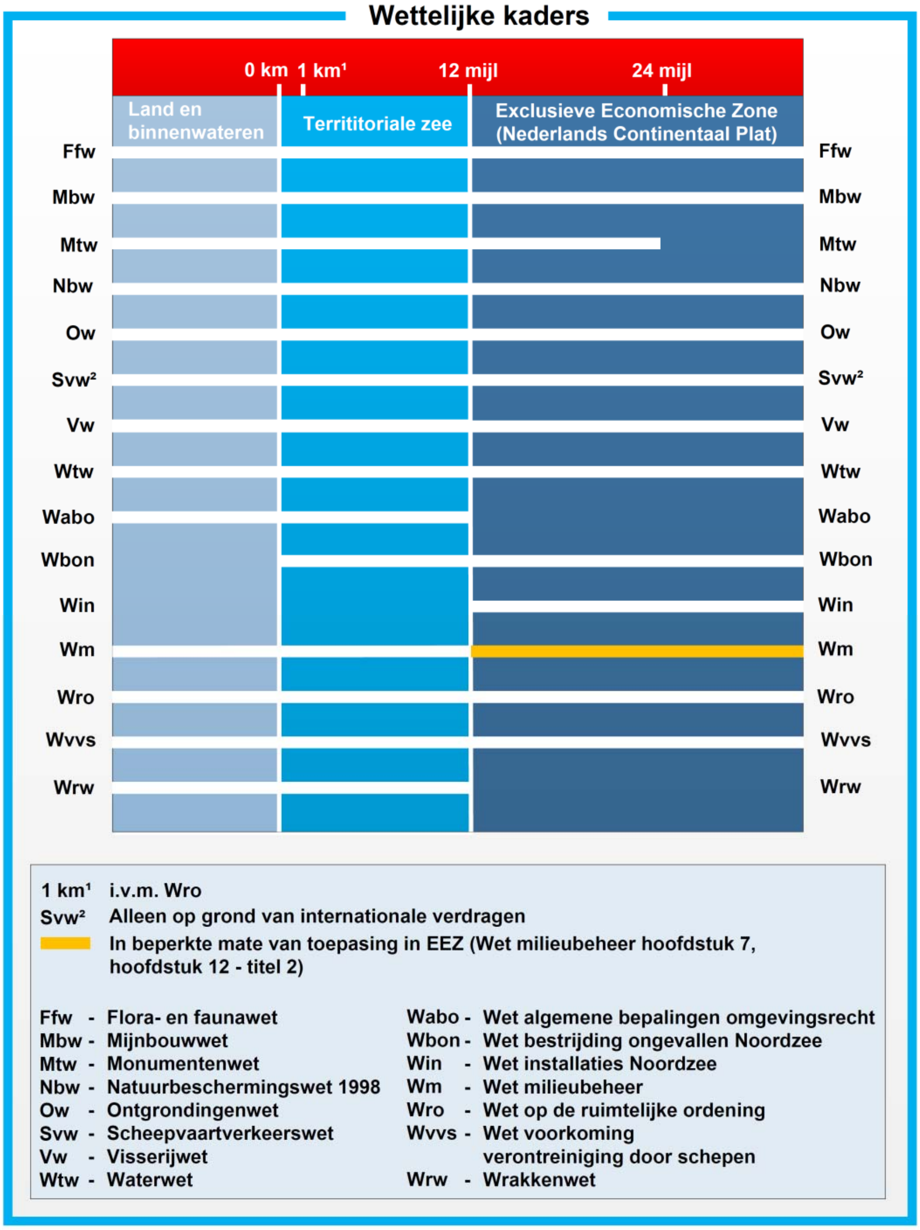


Figure 8: Laws implemented on Dutch waters (www.noordzeeloket.nl).

<u>Nature Conservation Law (NP Law) and Flora and Fauna act (FF Act)</u>
As of January 1 2014, the FF Act (species protection) and the NP Law (habitat protection) became applicable on the EEZ. Thus for any human activity that possibly has a negative impact on the marine environment or marine protected species, a permit through the NP law and exemption of the FF Act is required.

2.1.1 Pile driving: relevant policies

Regulations on pile driving

In the Netherlands a seasonal restriction is implemented (1 January- 1 July) in addition to the standard regulation (ADD and soft start), that the other neighbouring countries also apply (NP Law and FF Act). The vulnerable periods of seals, harbour porpoises and fish larvae and the possible effects of underwater noise on these animals were the reasons to implement the pile driving restriction period from January 1^{st} until July 1^{st} as a condition in the NP Law and FF- Act permit (Arends et al., 2009). Other conditions can be implemented in the permit depending on location and period.

Regulations on underwater noise mitigation differ greatly between the countries bordering the North Sea. Standard regulations in each country include the use of acoustic deterrent devices and a soft start. In some countries additional regulations have been implemented.

For example, in Germany a noise limit is implemented. When constructing a wind farm on the German EEZ the noise limit of SEL(single stroke) 160 dB re 1 μPa^2s (SEL at 750 m) or 190 dB re 1 μPa^2s peak to peak cannot be exceeded (Schallschutzkonzept, 2013). This is a strict condition which developers need to abide to in Germany and can only be reached by taking technical mitigation measures. For areas, important for the harbour porpoises, such as Sylt, disturbance of maximum 1 % of the Sylt area is allowed; for other areas this is 10% of the German EEZ (North Sea). Other conditions, such as implicit monitoring (noise monitoring) and static monitoring for the harbour porpoise, applying deterrents such as ADDs, and the use of a soft start, are often standard conditions that are included in the permit.

The United Kingdom on the other hand, follows the Joint Nature Conservation Committee (JNCC) guidelines (JNCC, 2010). Within these guidelines the use of a Marine Mammal Observer (MMO) and Passive Acoustic Monitoring (PAM) is obligatory. There is no noise threshold. Before performing the activity it should be certain the best available techniques are being used. There are exclusion zones based on important fish spawning grounds

In Belgium a restriction period (from May to August) is implemented. Like in Germany, Belgium has also implemented a noise threshold of 185 dB re 1 μPa^2(zero to peak) at 750m (pers. Comm. A. Norro) which is comparable to the German threshold of 190 dB (peak to peak). This threshold for pile driving is derived from the German legislation.

In Denmark harbour porpoises should not be exposed to a cumulative SEL (SEL_{cum}) of 183 dB re 1 μPa^2s or more. This noise threshold is based on a model which takes into consideration that the marine mammals have been scared/ deterred up to 2 km away from the site. In the model it is also considered that the animals flee by 1.5 m/s (interview DONG Energy, Engergi Styrelsen, 2014). Energi Styrelsen has set guidelines to measure and calculate underwater noise during construction of offshore wind farms (Energi Styrelsen, 2014).

Country	Exclusion Zone	Acoustic deterrent devices	Seasonal restrictions	Soft Start	Noise threshold	Passive Acoustic Monitoring
Netherlands	No	x	x (pile driving restriction 1 Jan - 1July) *NB. NL is currently reconsidering its policy towards a noise threshold*	x	No	No
Belgium	No	x	x (pile driving restriction 1 Jan – 30 April)	x	185 dB re 1 μPa^{2}s (zero to peak) at 750 m.	No
Denmark	No	X (not standard)	No	X (not standard)	SEL_{cum}183 dB re 1 μPa^{2}s[8])	No
Germany	x	x	X	x	160 dB re 1 μPa^{2}s SEL at 750 meters)	x
United Kingdom	X (mostly for fish spawning grounds)	X (not standard)	No	x	No	x

Table 5: Comparison of regulations for noise mitigation per country. Information from interviews (BSH, BFN, JNCC, DONG; see appendix).

Policy offshore wind in the Netherlands

In the Energy agreement for sustainable growth in The Netherlands 40 public sector and private sector parties agreed to achieve a capacity of 4,450 MW in offshore wind farms by 2023. This means a total of 3,450 MW must be tendered in addition to the existing and prepared wind farms (1,000 MW). The table below shows the planning of tendered and operational capacity of offshore wind farms as agreed in the Energy Agreement.

Tender in	Capacity (MW)	Total (MW)	Operational in
2015	700	700	2019
2016	700	1.400	2020
2017	700	2.100	2021
2018	700	2.800	2022
2019	700	3.500	2023

Table 6: Tender program offshore wind in The Netherlands

Furthermore, developers of offshore wind farms are granted an SDE+ subsidy[9] adjoining the concession, under the condition to achieve a reduction of the cost price of 40% in the period 2015-2019.

[8] assuming marine mammals have been deterred 2 km from the site and flee with a speed of 1.5m/s

[9] “Stimulering Duurzame Energieproductie”, the Dutch subsidy scheme in which producers receive a grant to compensate the unprofitable component of operating an installation for the production of renewable energy.

Based on the Energy agreement, the offshore wind industry has the following challenges in the period 2015-2019, which may be influenced by regulations on pile driving restriction period or required noise mitigating measures:

- Ability to reduce the cost price
- Sufficient time for construction of offshore wind farms

2.1.2 Seismic research: relevant policies

Policies in the Netherlands:

<u>'Kleine velden beleid' (small gas field policy)</u>
The small fields' policy (Derde Energienota, Ministerie van Economische Zaken, 1995) is aimed at promoting exploration and production of small natural gas fields, both onshore and offshore. It is considered of great national economic importance as it ensures that the Groningen field can serve longer as a key provider of flexibility and volume to the market, giving The Netherlands a strong economic position (pers comm. Robert van der Velde, RHDHV). Specifically, the Dutch Gas Law ensures that there is a buyer at market conditions (GasTerra) for gas produced from the small fields.

<u>Mijnbouwwet (mining law)</u>
Exploration and production of minerals including gas and oil reserves are regulated in The Netherlands through the Mining law known as the 'Mijnbouwwet'. The mining law covers the Dutch main land as well as the EEZ. This law mostly regulates the technological measures that apply to exploration and production of minerals.

<u>JNCC Guidelines</u>
In the JNCC guidelines a 20 minute soft start is recommended. However, in the Dutch permits, granted in preparation for seismic research, a soft start of 30-60 minutes was often required (NP law permit Hansa (2014), FF-act exemption NAM and Sterling(2014).

The JNCC guidelines require the use of a trained Marine Mammal Observer (MMO). A MMOs role is to advice the company on the guidelines prior to the activity and conduct pre-shooting searches for marine mammals. Furthermore, the MMO is responsible to complete the JNCC reporting forms, including the MMO report. If seismic surveys are planned to start during hour of darkness or low visibility, it is considered best practice to deploy Passive Acoustic Monitoring (PAM) (JNCC, 2010).

Additional guidelines for seismic surveys suggested by JNCC (2010):

1. Pre-shooting search: prior to shooting a minimal 30 minute visual assessment needs to be done to determine if any marine mammals are within 500 meters of the centre of the airgun array.
2. Survey delay if marine mammals are detected within the mitigation zone (500 meters). Delay of 20 minutes from the moment of the last sighting is required prior to starting the soft start if a marine mammal was within the exclusion zone.
3. Soft Start: 20 minutes prior to shooting.

The JNCC guidelines, the harbour porpoise protection plan and the Ascobans agreement (Ascobans 2010) are used to formulate conditions in permits (FF Act and NP Law).

Policies in other European countries:

Compared to regulations implemented for offshore wind farms there are no/few specific regulations concerning underwater noise specifically for seismic surveys conducted on the North Sea. The companies interviewed mostly have experience operating in the United Kingdom (UK) and Germany. However, currently it is not possible for these operators to conduct seismic surveys in Germany. The paragraphs below contain a short description of the differences in regulations for offshore seismic surveys in the UK and Germany.

United Kingdom:
Requirements for seismic research in the UK are similar to the requirements in the Netherlands. In the UK, guidelines formulated by JNCC (see text frame above) are applied. The UK requirements differ slightly to the standard requirements in the Netherlands. According to the JNCC guidelines in the UK it is required to have a trained MMO on board the seismic research vessel in addition to a soft start. The use of a pinger is not part of the standard requirements in the UK (interview JNCC).

Germany:

In Germany there are no specific requirements concerning underwater noise for seismic surveys. The 160 dB re 1 μPa^2s (SEL at 750 m) threshold was implemented specifically for the construction of offshore wind farms using piling, however the German authorities are currently considering implementing a similar threshold for seismic research (pers comm Thomas Merck). The Sound Protection acts states that: ‘On account of the lack of data available, however, other sound sources that (may) lead to noise exposures, such as the noises emitted by offshore wind turbines during operation, noise from shipping activity, civilian and military sonar systems, and seismic explorations, are not examined in this Sound Protection Concept in terms of either their direct or their cumulative effects. Nevertheless, where they are known, the corresponding cumulative effects caused by these and other possible sound sources must be taken into consideration on a case-by-case basis as part of the Appropriate Assessment of projects under the Habitats Directive

Currently there is no seismic activity on the German EEZ. This is possibly also due to the regulations stated in the Sound Protect Concept (BMU, 2014) that the impacted area during an activity has to be limited to 10% of the German EEZ of the North Sea. In addition in the months May- August in the area of Sylt, specially protected by the Habitats Directive, the impacted area is limited to 1%. During this period it is mating season and harbour porpoise calves are born, thus the harbour porpoises are more vulnerable for disturbance (BMU, 2014).

2.1.3 Shipping: relevant policies

The Netherlands

In The Netherlands, there are many laws, policies and regulations related to shipping[10]. The most important Dutch law related to shipping as an activity is the shipping traffic law. However, there is no legislation on the production / reduction of underwater noise due to shipping. Most policies are regulated through the International Maritime Organization IMO. As a member, the Netherlands can influence the proposed IMO policies.

Until now, there are very few restrictions concerning underwater noise for shipping in The Netherlands. There are only restrictions for fisheries and fisheries research vessels, through guidelines stated in CR209 (international requirement). The CR209 states that the propellers should be free of cavitation and when the ship has a speed of 11 knots or more it should be provided with a diesel - electric propulsion.

Classification firms are currently producing guidelines, e.g. DNV silent class especially for fishery boats and fishery research vessels, as well as research vessels for seismic surveys. Also cruise ships are on the list. There are ongoing investigations on noise production of cruises and whether the cruise boats fulfil the silent class requirements. Until now no vessel meets the DNV Silent Class requirements.

In North-West Europe, there are no quantitative and/or qualitative restrictions on underwater noise production due to shipping. As a consequence very little information is available on this matter.

IMO has published guidelines to reduce underwater noise from commercial shipping which addresses adverse impacts on marine life (IMO, 2014). Following these guidelines is not mandatory. Only when constructing new ships (design and building), these guidelines may be (partly) considered. The Dutch Royal Association for shipping companies was involved in drafting the guidelines. However they have insisted on a holistic approach, when adaptations on an engine are being made also the rest of the ship should be mitigated for noise. Furthermore the Dutch Royal Association believes that a good measuring method for underwater noise due to shipping and the sufficient collection of good data are needed before the guidelines can be embedded into national legislation (pers. Comm. N. van de Minkelis, KVNR). An overview of IMO guidelines and possible measures for reduction of underwater noise is included in the table below.

[10] Ballast water convention, policy on shipping (2008), Convention of Bonn, Planologische kernbeslissing (PKB) Wadden Sea, IBN2015, MARPOL conventions, National Water plan, Policy on shipping traffic, Structural Plan PMR (2006), Policy on counteraction on pollution due to shipping, convention on wreck clean up, Policy on wrecks, convention on maritime law and IMO.

Design considerations	Propellers (reduction of cavitation)	Hull design	On board machinery	Technologies for existing ships	Operational and maintenance considerations
Hull form	Hull form, propeller design (diameter, blade number, pitch skew and sections)	Homogeneous wake fields	Location and optimization of foundation structures	New state of the art propellers	Propeller cleaning
Hull and propeller design together	Controllable pitch propeller	Structural optimization to reduce excitation response and transmission of noise to the hull	Diesel electric propulsion and electric motors	Wake conditioning devices	Underwater hull surface
	Cavitation test facilities		Technical adjustments such as engines on resilient mounts, vibration isolators	Air injection to propeller	Selection of speed (fixed and controllable pitch propellers)
	Fixed peak fluctuating pressure		Vibration isolation mounts and improvement of dynamic balancing		Re-routing of ships
	Propeller design options				

Table 7: Overview of IMO guidelines and possible measures for reduction of underwater noise.

Ships are generally not adapted to reduce underwater noise; rather, they are optimised for fuel efficiency. When changes are made to ship components, such as the propeller or the hull form, for reasons of fuel efficiency, a good opportunity may arise to optimise new component designs for lower underwater noise as well.

2.1.4 Definition baseline alternative

For each selected activity a baseline alternative with related measures is defined. The baseline alternative represents current[11] restrictions and mandatory measures in legislation and permits for that particular activity.

The baseline alternative comprises the following characteristics per activity as discussed with Rijkswaterstaat:

- Pile driving:
  - Pile driving restriction period in the North Sea (Dutch EEZ) from January 1st to July 1st
  - Permit requirements: application of soft start and acoustic deterrent devices (ADD's)

[11] as of January 2015

- Seismic research:
  - Permit requirements: application of soft start and acoustic deterrent devices (ADD's)
- Shipping:
  - No national (Dutch EEZ) restrictions or mandatory measures
  - Recommendation to follow the international guidelines by IMO

2.2 Alternatives for pile driving

2.2.1 Introduction to pile driving

Pile driving is an activity that is part of the foundation installation process of an offshore wind farm. During various feasibility studies, a developer of an offshore wind farm chooses among different options for the foundation techniques for the wind turbines to be constructed. The choice for a foundation technique among others depends on the local water depth, local soil conditions, expected construction time of the foundation and costs. The most foundation techniques that are feasible (at this moment or in the near future) for offshore wind farms in North-West Europe are: monopiles, gravity based structures (GBS), jackets and tripod foundations. Pile driving is required to secure all these foundations to the sea bottom except for GBS. Other possible types of foundation are still in development and are unlikely to be applied on large scale before 2020. Besides all kind of early stage developments, suction based and floating foundations are promising techniques that are worth mentioning. These foundation techniques can be applied without pile driving.
At the conference organised by BSH, Bellmann et al. (2014) presented the reduction in dB (SEL) for different mitigation techniques (see table below). It is shown that different techniques have a different efficiency in reducing noise, but also that combining two techniques does not mean that the reduction of noise per technique can be added up.

Nr.	Schallschutzsystem	ΔSEL [dB]	Anzahl
1	Single Big Bubble Curtain - BBC (> 0,3 m^3/(min*m), Ballastierung außen, Wassertiefe < 30 m)	10 ≤ 13 ≤ 15	> 150 (> 300)
2	Double Big Bubble Curtain - DBBC (> 0,3 m^3/(min*m), Ballastierung außen, Abstand > Wassertiefe, Wassertiefe < 30 m)	14 ≤ 17 ≤ 18	> 150 (> 300)
3	Small Bubble Curtain – SBC (verwendete Luftmenge, Lochkonfiguration)	(5) ≤ 10 ≤ 14	2
4	Hydro Sound Damper (Anzahl und Größe der HSD Elemente)	8 ≤ 10 ≤ 13	> 10
5	Noise Mitigation Screen – IHC-NMS (Abstand zwischen innerem und äußeren Rohr)	10 ≤ 13 ≤ 15	> 140
6	Kofferdam / Rohr-in-Rohr Konstruktion (Dichtigkeit der Dichtungslippen)	problems < 10 no problems ≥ 20	< 10 (> 10)

Schallminderung: $\Delta L_{Peak} \geq \Delta SEL$

Kombinationen

Nr.	Schallschutzsystem	ΔSEL [dB]	Anzahl
7	Kombinationen aus BBC Systemen (DBBC + BBC)	15 ≤ 16 ≤ 19	> 30 (> 70)
8	Kombination IHC-NMS + BBC	17 ≤ 19 ≤ 23	> 90
9	BBC (HTL) + HSD	15 ≤ 16 ≤ 20	3
10	DBBC (Weyres)+ HSD	14 ≤ 16 ≤ 22	2
XXX	Halbierung der Rammenergie	Zusätzlich 2,5 dB	

$$\textbf{ABER: } \Delta SEL_{System\ 1} + \Delta SEL_{System\ 2} > \Delta SEL_{Kombination}$$

$$13\ dB_{System1} + 13\ dB_{System2} \neq 26\ dB_{Kombination}$$

Table 8 : Overview of the reduction of underwater noise by mitigation measures (presentation Bellmann et al., 2014).

The reduction of noise influences the disturbed area for sea animals (see table below).

dB re 1 μPa^2 s SEL at 750 m	Influenced radius (r in km)	Influence area Km^2
without mitigation	about 25	1.963
160	8	200,96
155	5	78,5
150	3	28,26

Table 9 : Indication of the reduction of the impacted area at different noise levels without and with noise mitigation (interview BSH).

Furthermore, different mitigation measures cause different delays in construction. For example, when using a bubble curtain, an extra ship can be in place when the construction ship arrives which diminishes the delay. The delay for noise mitigation by isolation casings (e.g. the IHC system) can be larger as less monopiles can be transported by ship and more shipping is needed to fetch monopiles in the harbour. The difference in delays between measures is due to lack of detailed information not further quantified in this study.

In the table below, an overview of pile driving alternatives is given and also an explanation why these alternatives are included in this SCBA or not.

Pile driving alternatives	Alternative	Why/why not included
alternative pile driving methods	Not applicable	These methods are still being developed and costs cannot be quantified. Thus not included in this SCBA.
structure and design	Not applicable	No data available on cost thus not included in SCBA.
noise mitigation measures for impact pile driving	Alternative "No restriction period"	A few of these techniques such as a cofferdam and a bubble curtain are included in the SCBA as developers have experience with these systems in Germany. Costs per individual technique were not available, only costs of a combination of noise mitigation measures were acquired.
low-noise foundations	Not applicable	Not included in SCBA because it is still in research and development and no data on costs were available.
preventive measures	Baseline alternative	Standard measures applied by the offshore wind industry. Cost could be partly quantified and therefore included in this SCBA.

Table 10 : Overview of alternatives for pile driving and the reasons why they are included in the SCBA or not.

In appendix E the characteristics, advantages and disadvantages of all foundation techniques are explained.

The relevant areas that are designated by the Minister of Infrastructure and Environment as areas for offshore wind in the Dutch EEZ of the North Sea in the time horizon up to 2023[12], Borssele, Hollandse Kust Noord en Zuid, have a maximum water depth of about 30 meters. Offshore wind farms in The Netherlands (Luchterduinen and Gemini), Germany and United Kingdom, that are currently developed or will be in the near future at comparable water depths, apply monopile driving as foundation method.
Because of the water depth of 30 meters at the designated areas in Dutch EEZ, the large scale experience by contractors and efficiency, monopile driving is expected to be the most appropriate and feasible foundation method in the near future.

For monopile foundation several methods could be used to bring the foundation into the soil:

- Hammering: pile driving with a hammer
- Vibratory pile driving
- Drilling.

[12] Letter to parliament minister of Economic Affairs, November 2014

Hammering takes place for about 1 to 3 hours per monopile, depending on several factors, such as type of soil. In a heavy clay soil hammering is much more difficult than in a sandy soil. Each monopile is hammered into the soil until about 30 to 35 meters.

In vibratory pile driving, a vibratory hammer is used in place of an impact hammer. Often vibratory pile driving needs to be combined with impact pile driving to make sure the pile is driven to the preferred depth. The time of vibratory pile driving is about a half an hour per pile, which is shorter than hammering a pile. This technique is still being tested by contractors and is not expected to be applied on a large scale before 2020. Certifying institutions are not yet convinced that the pile is stable enough by vibrating only. For example, for offshore wind farm Luchterduinen vibratory pile driving is assessed as possible technique, but not applied due to soil conditions. According to contractors, vibratory pile driving can be applied in sandy soil but is much less appropriate in clay soil.

Drilling is an innovative technique that is not applied on a large scale in the North Sea. By drilling rather than hammering the amount of underwater noise can be reduced. However, contractors indicate that a pile requires another design and a larger weight which has a negative effect on costs compared to hammering.

Both the industry (developers, contractors) and research institutes indicate that the selection and application of pile driving techniques and accompanying noise mitigating measures cannot be generalized to derive best practice measures that can be applied at every wind farm. Per location and size of the wind farm different conditions determine the methods of construction and development of the wind farm.

For each individual offshore wind farm, a long term process is needed to select an appropriate firm specific system for noise mitigation (BSH, 2014, workshop). BSH indicates the following phases of this process:

- Analysis and Preparation (up to 1.5 years)
- Detailed design, engineering and manufacturing (up to 2 years)
- Implementation (4 months to 2 years).

2.2.2 Project alternative pile driving

Both Rijkswaterstaat and the industry indicated that the main question is: how does the current seasonal restriction compare to a situation without a restriction, but with mitigating measures. Therefore, the project alternative “no restriction period” has been devised as follows:

- Mitigating measures: measures to mitigate underwater noise to comply with the limit of 160 dB re 1 μPa^{2}s (SEL at 750 m) without pile driving restriction period – a regulatory limitation, applied in Germany which is used as a guideline for this SCBA. In other countries other limits are being applied. In this study we chose the German limit as the TNO study (TNO, 2015) is using this limit to describe effects on harbour porpoises disturbance days. To use the noise thresholds used in other countries, like Denmark or Belgium, additional research should be done first to receive information about the amount of harbour porpoise disturbance days, but also for information on costs.

- Focus of mitigating measures is on technical mitigation measures that reduce noise at the source and accompanying technical measures to mitigate noise from pile driving. These techniques have been included in appendix B. The techniques include i.a. sleeves of steel around monopoles and e.g. bubble curtains.
- Furthermore, it is assumed that 700 MW (2 wind farms of 350MW each) will be realised every year based on the tender program offshore wind energy (see also table 6).

Because of a lack of more detailed information, the different measures' individual cost effectiveness (and therefore, efficiency) cannot be researched in the SCBA. It is recommended that more research is conducted in this field[13].

2.3 Alternatives for seismic research

For seismic research, the following types of measures are acknowledged based on expert judgement:

- Procedural measures, in practice a seasonal restriction
- Conducting fewer seismic surveys to reduce underwater noise by reprocessing of existing data, and effectively reducing the number of seismic surveys by 50%.

2.3.1 Alternative mitigation measures

Currently there are little to no feasible alternatives available on the market for the airguns used to conduct seismic research (interviews E&P industry). Standard mitigation measures to prevent injury or harm to marine mammals, such as the soft start and the use of an ADD, already are standard protocol during the seismic surveys. Csa Ocean Sciences Inc. (2014) collected a large amount of information on possible quieting technologies that reduce noise production for seismic surveys as well as pile driving. Though some techniques sound very promising, most of these alternatives are still in research and development (see table below and Appendix D).

[13] Appendix B contains a more detailed description of different noise mitigating and preventive measures

Seismic survey alternatives	Alternative	Why/why not included
Technical and procedural modifications	Baseline alternative and alternative "Procedural measures"	Marine mammal deterrent measures are applied in the baseline alternative. Alternative "Procedural measures" includes a seasonal restriction which doesn't decrease the amount of underwater noise; Continuous line acquisition is not included in the SCBA. This method has been applied, but is hardly mitigating the noise production; it reduces the impacted area slightly.
Alternative sources e.g. eSource, reduced airgun output , Marine Vibroseis (MVs) and powerdown	Not applicable	The technique is still in research and development; smaller output of airguns leads to poor quality of data. Marine vibroseis is still in research and development. It is a technique with high potential to be applied in the future after 2020.
Low Frequency Acoustic Source (LACS)	Not applicable	Little to no experience with these technologies.
Noise containment (reduce unwanted noise by e.g. bubble curtains, parabolic reflectors and airgun silencers)	Not applicable	The techniques are difficult to apply due to the extensive area and the moving noise source.
Complementary Technologies	Alternative "Fewer surveys"	The alternative is described as 50% less seismic surveys and reprocessing of data. Reinterpretation of data is a technique that already exists and thus can be included in this SCBA. However, the data are not always accurate and chances on a dry well are increasing.

Table 11 : Overview of alternatives for seismic surveys and the reasons why they are included in the SCBA or not.

An overview of mitigating measures can be found in Appendix D. Marine vibroseis, and/or an alternative low frequency source airgun, seem to be the most promising techniques when it comes to noise reducing measures for seismic research and therefore these measures are further described below.

<u>Alternative sources</u>

Marine Vibroseis

Vibroseis is a technique that is already commonly used on land, but has seen limited use in the marine environment. This method uses a seismic vibrator which propagates energy into the earth over an extended period as opposed to the near-instantaneous energy provided by airguns (CSA Ocean Sciences Inc., 2014). It uses a signal which is a group or sweep of frequencies i.e. between 10-80 Hz. Hence, compared to airguns the instantaneous sound pressure level is much lower (OGP, 2011). Though this technology seems to be a good alternative solution for airguns, the seismic data acquired through this technique is not equivalent to that acquired by standard seismic acquisition. In addition it is not yet clear if marine vibroseis actually reduces negative impact on marine mammals (interview E&P Industry). Currently the Marine Vibroseis Joint Industry Program, which is sponsored by large developers in the E&P industry such as Shell, ExxonMobil and Total, are pursuing development of this technology. This program is anticipated to be completed by the end of 2016 (Rosenbladt, Jenkerson and Hullevigue, 2013).

eSource airgun
eSource is considered a marine 'friendly' airgun which is produced by Bolt Technologies. The eSource is not an alternative to the use of airguns, but does aim to reduce the excess residual noise above 100 Hz that is produced by standard airguns.

<u>Methods to reduce noise from airguns</u>

Bubble curtain
This is a commonly used technique to contain noise during pile driving. The CSA Ocean Sciences Inc. (2014) suggests that it can also be used during seismic surveys. However, it is much more difficult to apply as the area for seismic surveys is extensive and non-static.

<u>Procedural modifications</u>

Continuous line acquisition
Continuous line acquisition (CLA) is an innovative procedural method which can reduce the time of the survey and minimize the area which the survey ship has to cover. During CLA the seismic vessel doesn't sail along parallel lines but in a semi-circular pattern. During the curves in CLA, the airguns are being used, while in the traditional surveys the airgun is turned off for calibration during the curves (see 1.2.4). CLA doesn't reduce the amount of noise produced by the airguns but it does reduce the total survey time and thus the number of marine mammal disturbance days, but also slightly the impacted area. This technique cannot be applied in all situations.

<u>Temporal and spatial restrictions</u>

Seasonal restrictions in and around Natura 2000 area
Prior to a seismic survey an appropriate assessment is done to assess the environmental impact of the survey on the marine environment. When in or near a Natura 2000 area, such as the Noordzeekustzone or Doggers Bank on the North Sea, it is often suggested and required, that the activity takes place outside the vulnerable period of the protected species. In addition, it is also preferred for seismic surveys to take place when the number of marine mammals or birds in the area is low, thus reducing the number of disturbed animals. This means that a survey in the fall will have a lower impact compared to a survey executed in the spring when the number of harbour porpoises in the Dutch North Sea is highest. In the fall the weather conditions

can cause delay and in turn the survey will take longer. When a survey takes longer, the sound exposure time of marine mammals is being increased.

Conclusion

This leaves two alternatives: 1) Procedural measures such as seasonal restrictions (January 1 to July 1) plus application of soft start and acoustic deterrent devices (ADD's) and 2) 50% fewer seismic surveys and reprocessing of data. The last alternative is based on expert judgement.

2.4 Alternatives for shipping

For shipping, the following types of measures are acknowledged based on expert judgement:

- Procedural measures: speed reduction.
- Technical measures to comply with a reduction of 10 dB re 1 $\mu Pa^2 s$ by e.g. adaptation on propeller design, machinery isolation, hull (romp) design and surface. The 10 dB re 1 $\mu Pa^2 s$ reduction of underwater noise is based on expert judgement from MARIN, who is studying the possible mitigating measures for shipping in the SONIC project (pers. Comm. M. Flikkema). It is until now impossible to define a limit for underwater noise generated by ships, as too little information is known and variation between ship types is very large. However, adaptations on the hull or the propeller of ships can reduce under water noise.

Implementation of the IMO guidelines means that very large and expensive measures are needed. These guidelines can however gradually become implemented when building new ships. This means that after a few decades (approximately 25 years as this is a typical life cycle of a ship), the whole fleet can be replaced with more silent and environmentally friendly ships. To accomplish this, the IMO guidelines should become obligatory for new ships, which is currently not the case.

2.4.1 Shipping Alternative mitigation measures

<u>Preventing measures</u>
There are almost no preventive measures, except in highly sensitive and important areas with vulnerable nature (such as Alaska); these areas are not present on the NCP. Restrictions to reduce underwater noise are imposed by introducing speed limits. Some cruise ships want to spot whales, only these ships are adapted to produce very low underwater noise levels through the design of the hull form in combination with the design of the propeller and adaptation of the internal machinery (also for the comfort of tourists) (interview Marin). For military ships noise reduction probably also applies for military reasons.
Re-routing is another preventing measure that is globally implemented, but is not relevant in the Dutch EEZ. There are no such protected areas in the Dutch EEZ to re-rout shipping. At the coastal zone there are some restrictions for shipping especially for seals: a ship cannot come closer than 1,500 m from haul out places.

Mitigation measures

Mitigation tools for underwater noise are lower speed, different propeller design and ship design. In paragraph 2.1.3, an overview of the possible mitigation measures as proposed by IMO (2014) is given.

Cavitation is the main source of underwater noise. The two major aspects that influence the level of cavitation are propeller design and wake flow into the propeller. By improving the propeller design, either through modifying the existing propellers or by fitting new propellers designed with noise reduction of hydro-acoustic noise, noise reduction of the noisiest merchant ships can be achieved, and propulsive efficiency increased (Renilson, 2009). Other types of ships may need different mitigation measures for noise reduction e.g. by fitting appropriately designed appendages such as wake equalizing ducts, vortex generators or spoilers. For new ships, the wake flow can be improved through a more careful design, which will require an increased design effort, including careful model testing and computational fluid dynamics analysis. Concerning optimisation of the back part of the ship, new developments aim to achieve the most favourable design of the hull including the interaction with the screw propeller. The form of the ship is important to minimalize cavitation (interview Marin).

In the sixties and seventies of the previous century, the navy put a lot of effort in reducing noise as a consequence of cavitation. After that, the attention shifted towards cavitation inception, e.g. the speed at which cavitation occurs and noise levels start to increase. This is one reason why so little information is available on measures to prevent underwater noise (interview). Some knowledge is available on pressure fluctuations; these are low up to 200 Hz. These aspects are part of the SONIC project, due to deliver its results in October 2015.

The table below gives an overview of the chosen alternatives or shipping in this SCBA.

Shipping alternatives	Alternative	Why/why not included in the study
Operational changes	Alternative "Procedural measures"	Reduction of speed is included in this SCBA. Alternative shipping routes is not included as this is not a realistic option for the Dutch EEZ.
Optimizing Propeller design	Alternative "Technical measures"	Can be used to realize a noise reduction however no data is available on the costs of these measures. The costs are thought to be very high and vary depending on ship type.
Optimizing machinery	Alternative "Technical measures"	Can be used to realize a noise reduction however no data is available on the costs of these measures. The costs are thought to be very high and vary depending on ship type.
Hull design	Alternative "Technical measures"	Can be used to realize a noise reduction however no data is available on the costs of these measures. The costs are thought to be very high and vary depending on ship type.
Noise mitigation systems	Alternative "Technical measures"	Can be used to realize a noise reduction however no data is available on the costs of these measures. The costs are thought to be very high and vary depending on ship type.

Table 12 : Overview of alternatives for shipping and the reasons why they are included in the SCBA or not.

2.5 Summary overview of alternatives

The table below provides an overview of the baseline alternative as well as the project alternatives for all activities.

Activity	Baseline alternative	Alternative 1	Alternative 2
Pile driving	*"Baseline alternative"* Pile driving restriction period in the North Sea (Dutch EEZ) from January 1st to July 1st Permit requirements: application of soft start and acoustic deterrent devices (ADD's)	*"No restriction period"* No seasonal restriction Permit requirements: application of soft start and ADD's Threshold sound level 160 dB re 1 μPa^{2}s (single strike SEL at 750 m)	N/A
Seismic research	*"Baseline alternative"* Permit requirements: application of soft start and acoustic deterrent devices (ADD's)	*"Procedural measures"* Procedural measures such as seasonal restrictions (January 1 to July 1) plus application of soft start and acoustic deterrent devices (ADD's)	*"Fewer surveys"* 50% fewer seismic surveys by reprocessing of data
Shipping	*"Baseline alternative"* No national (Dutch EEZ) restrictions or mandatory measures Recommendation to follow the international guidelines by IMO	*"Procedural measures"* Procedural measures: Speed reduction	*"Technical measures"* Reduction of 10 dB re 1 μPa^{2}s by taking technical measures, such as: Propeller design; Machinery isolation; Hull (romp) design and surface.

Table 13 : Overview of baseline alternative and project alternatives for all activities

3 ECONOMIC ASSUMPTIONS AND PRINCIPLES

3.1 Physical effects versus welfare effects

Welfare effects are both monetary and non-monetary impacts of a project or policy on the prosperity of a country or region. For example, if infrastructure for local residents causes noise and this negatively affects their quality of life, this is a negative welfare effect of the infrastructure project.

The SCBA is a *welfare economic* assessment in which the concept of economy should be interpreted broadly: all the project's effects from which consumers derive utility should be included in the assessment. This 'utility' is operationalised by examining what consumers are willing to pay (or to receive as compensation) for an effect.

The economic approach chosen in SCBA analyses means that not all effects that are observed (physical effects) are also welfare effects. Only effects that affect the welfare (prosperity) of the geographical region will be included in the SCBA. An example would be noise: noise is a *physical effect* that can be perceived and measured. In itself, noise is *not* a welfare effect. However, the effects caused by noise, such as health effects, *are* welfare effects. In the case of underwater noise, noise itself is a physical effect and is therefore not taken into account, whereas the impact of the noise on marine mammals is a welfare effect and therefore included.

Economic effects for underwater noise[14][15]

Figure 9 shows conceptually what the economic impact of underwater noise is for society. The presence of underwater noise might potentially cause economic damage to society by its influence on marine life, and this is illustrated by a marginal damage cost curve (MDC) which increases with the extent of underwater noise. The marginal damage costs are the increase in total damage costs when the extent of underwater noise increases with one unit. This suggests that the benefits of reducing underwater noise are equal to the damage costs that can be avoided thanks to a reduction in underwater noise.

On the other hand, reducing underwater noise might require resources. This is illustrated by the other curve in the figure, which illustrate the marginal reduction costs (MRC). These costs are the increase in total reduction costs when the extent of underwater noise is reduced by one unit. Typically, measures for reducing underwater noise are likely to be increasingly expensive the more noise is to be reduced, which explains that the marginal reduction cost curve is increasing for movements from the right to the left along the x axis, i.e. when the extent of underwater noise is reduced. However, the measures could also introduce benefits in terms of technological improvements. One way of introducing such types of benefits in Figure 9 is to subtract them from the marginal reduction costs, i.e. moving the marginal reduction cost curve downwards.

The graph also suggests that given that the present extent of underwater noise is N^0, it is profitable to society to reduce the extent underwater noise with one unit, because for this change the benefits, i.e. the reduction in damage costs, is greater than the increase

[14] While this paragraph focuses on underwater noise, a similar approach may be valid for other welfare effects.

[15] Economic Impact of Underwater Noise, Tore Soderqvist, 29 April 2014

in reduction costs. The same is true for all reduction until marginal damage costs equal marginal reduction costs, i.e. at N*.

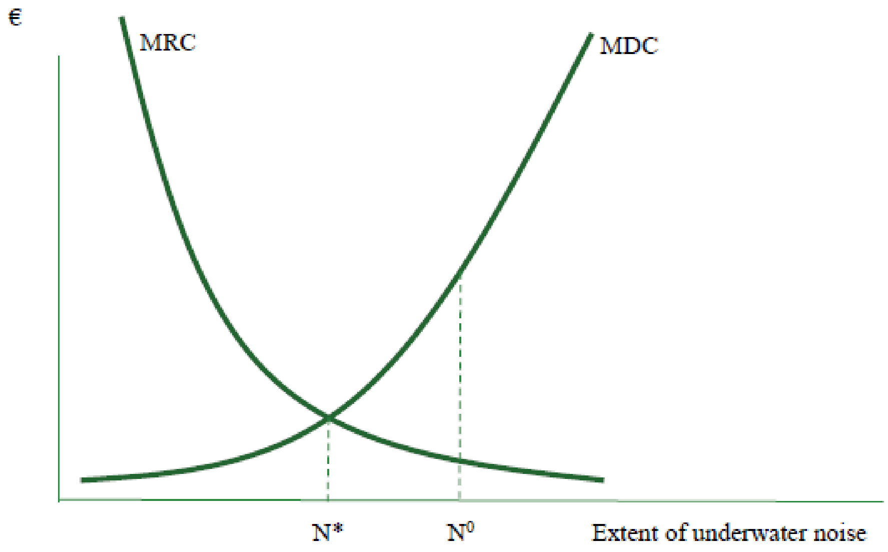


Figure 9 : Marginal damage costs (MDC) of underwater noise and marginal costs of reducing (MRC) underwater noise

3.2 Direct effects versus indirect effects

In many SCBAs a distinction is made between direct and indirect effects. In the SCBA for underwater noise too, some effects will be derived from other effects. Specifically, the effects can be defined as follows:

- Direct effects are the costs and benefits that can be directly linked to the owners/users of the project properties (i.e. the costs and benefits that have an immediate impact on the project's market).
- Indirect effects are the costs and benefits that are *passed on* to the producers and consumers outside the market with which the project is involved (for example, the price increase of power generation due to a higher cost of pile driving).
- A third category, so-called external effects are the costs and benefits that *cannot be passed on* to any existing market because they relate to issues such as the environment (emission of CO_2 etc.), safety (traffic, external security) and nature (biodiversity, dehydration etc.).

It cannot be stated that any of these effects are more important than other effects (direct effects are by no means more important than indirect or external effects, per se). However, it must be said that it is often more difficult to determine the project's impact for indirect and external effects as markets' intertwined relationships cannot always be separated clearly.

3.3 Depth of the study: elements out of scope

The following aspects of underwater noise are not addressed in this study:

- This study mainly focuses on the effect of underwater noise on marine mammal disturbance days. This is largely based on expert judgment and existing literature.

An in depth analysis of impacts of underwater noise on the functioning of ecosystems is outside the scope of this study.

- Current restrictions and mandatory measures in the Dutch EEZ are the starting point of this SCBA and are briefly explained. An explanation of the origin and substantiation of reasons for the current policy are beyond the scope of this SCBA.
- Cumulative effects of underwater noise mitigating measures by different human activities in the Dutch EEZ are not described or elaborated. The SCBA focuses on the (cost) effectiveness of preventive and mitigating measures within the relevant activities.
- Certain effects that may occur with respect to the following aspects as a result of the execution of measures to mitigate underwater noise:
  - Health, Safety and Environment (HSE) aspects, which are recognized to be key issues in the operations of the industries, however, are assumed to be a condition in the execution of all offshore activities.
  - The value society adheres to the biodiversity of marine mammals in the North Sea
  - Water pollution
  - (Migratory) birds
  - Employment
  - Export of knowledge and technology
  - Delays in construction as a result of mitigating measures

It is concluded that the impact on employment and the export of knowledge and technology will be minor, especially as it is not clear how many *additional* jobs will be created in the project alternatives, and also, whether these are generated in the Netherlands or abroad. As this SCBA has a national scope, only effects relating to the Netherlands may be taken into account. As there is no conclusive information available on jobs and export value (and the fact that this effect is deemed relatively small[16]), these factors have not been taken into account.

3.4 Measuring effects: different approaches

In a SCBA, a comparison is made between different alternatives. To be able to make the comparison as accurately as possible, it is ideal to measure the effects using the same units. In a SCBA, where possible, these units are monetary, i.e. euros. The process of expressing effects in monetary terms (euros) is called monetisation.

To be able to monetise effects, a prerequisite is that one is able to quantify them first. However, quantification, and to even greater extent, monetisation, is not possible for all effects. Effects that cannot be quantified or monetised are presented in such a way that they can be compared. In this way, policymakers can include these effects in their final trade-offs. The method of monetising effects can also influence the outcome of a social cost-benefit analysis and predictions will always remain uncertain. Therefore, the results of a SCBA are not absolute. Nevertheless, it remains a useful instrument to investigate the strong and weak points of the different alternatives.

[16] Expert judgement

Alternative solution: creating an index number
Certain elements in this SCBA cannot be monetised or quantified. However, the SCBA attempts to find a solution to this problem, and uses a specific form of cost-effectiveness inspired by the Multi Criteria Cost-Benefit Analysis (MCCBA) (Sijtsma 2006, Sijtsma et al. 2011 and 2013; Van Puijenboek et al. 2014). MCCBA is a carefully designed combination of CBA and Multi Criteria Analysis (MCA) and is able to retain the analytical rigor of CBA, while allowing more flexibility in non-monetary measurements. In an MCCBA, it is not the monetary or non-monetary character of measurements that matters most, but rather the fact that the measurement is expressed on interval or ratio scales, preferably using standardized measurements (Sijtsma et al. 2011). In a MCCBA approach, monetary valuation is not an absolute necessity; whether or not it is possible is a matter of operational feasibility and data availability in each evaluation case.

The reason for the focus on standardised indices is that it allows for a more rigorous and in-depth ratio-analysis / cost-effectiveness analysis, since it allows for comparisons across different measures. The standardised effect measurement applied in this SCBA is the ‘number of marine mammal disturbance days’. Other than measurements expressed in e.g. decibels, it accurately measures an important social concern. Monetising, although ideally within a SCBA did not prove feasible at this moment within this project. The ‘number of marine mammal disturbance days’ can be applied as an index number for comparison of measures in the baseline alternative with alternative measures. Besides, this number can be easily understood by both economists and ecologists and because of its ratio scale measurement it is quite ideal for cost-effectiveness analysis.

In this SCBA an important effect is defined as the benefit of having less animal disturbance days in case of alternative measures compared to measures in the baseline alternative. A disturbance day is the product of the number of impulse days times the number of disturbed mammals (in this case harbour porpoises) per impulse day (keeping in mind the difference in seasons and the duration of the disturbance per impulse day) and applies well for pile driving and seismic surveys as these activities produce impulsive noise. Shipping produces ambient noise and not marine mammals, but probably fish are more sensitive to this type of noise. However, no useful measure has yet been developed for fish. Therefore the best available data will be used, in this case, marine mammal disturbance days. The definition of an impulse day is further explained below. It is assumed that the application of measures that prevent or mitigate underwater noise will disturb marine mammals to a lesser extent than compared to a situation in which these measures would not have been applied.

3.5 Reference years and time horizon

The principle of a SCBA is to work with an infinite time horizon. To adhere to this principle a full overview of all costs and benefits for each year in the future is required. Because a calculation for all future years is often not feasible in practice, a detailed analysis of the effects limited to one or two so-called reference years is undertaken instead. For the years in-between, before and after the reference year(s) inter- and extrapolation can be applied.

In practice, it is often not possible to use the same reference years for all effects, as not all underlying information is available for these years. In such instances, multiple years are used (one for each effect). Moreover, the 'infinite period' is usually shortened to 100 years for practicable reasons. In some cases another time horizon is used to capture the life of the project.

In this SCBA, a different time horizon is used for the three different activities that are being investigated (even though the effects of the present policy measures are being considered as the baseline alternative, the length of periods covered for the analysis of the alternative measures vary by activity):

- Pile driving: horizon of 7 years, from 2016 up to (but not including) 2023, based on the period in the TNO study (2015) and Energy Agreement for construction of offshore wind farms.
- Seismic research: between 2015 and 2044 (30 years), as this is the period in which the North Sea may be completely researched for oil and gas reserves.
- Shipping: a period of 25 years, as this is the typical lifecycle of ships.

It is understood that choosing different time horizons for the different activities reduces the ability to compare outcomes for different activities in this SCBA. However, there is a lack of sufficient data to correctly make this comparison. Therefore, it was decided that the time horizon for each activity will be in line with developments for that respective activity.

3.6 Scope

Apart from the scope description in this and the previous chapter, remaining scope items of this study are defined along the following elements:

- Selection of geographic area.
- Selection of marine species which are affected by underwater noise.
- Selection of industries for which preventive and mitigating measures for underwater noise are applied.

<u>Selection of geographic area</u>
The Dutch EEZ of the North Sea is selected as the study area in which the benefits and costs of measures are analysed. A study of restrictions and mandatory and applied measures for noise mitigation in adjacent countries (Germany, United Kingdom) was done by having interviews and using literature. This provides an insight into the availability and the (cost) effectiveness of these restrictions and measures in practice. This information is used as a comparison with the Dutch situation. In this report neither interpretation nor conclusions are drawn on the effectiveness of applied restrictions and measures in other countries. The outcomes of the study are valid for 'The Netherlands Plc' ('BV Nederland').

<u>Selection of marine species which are affected by underwater noise</u>
Various marine species in the North Sea are affected by underwater noise. Not all marine species are equally sensitive to underwater noise. For this SCBA the worst case is applied and therefore certain species of marine mammals are selected to analyse the effects and costs of preventing and mitigating measures for underwater noise. In this case the harbour porpoise is chosen as it is considered to be most sensitive animal for underwater noise as a result of impulsive sound in Dutch EEZ. For ambient sound, fish are probably more sensitive and effects are qualitatively described in Appendix A. The effects of measures on other marine species including whales, dolphins and birds are

not addressed in this report, since too little information is available. In chapter 1.2.2.and appendix A, the scope for marine animals and the reason why they are selected, are described and elaborated.

Selection of industries

Anthropogenic underwater noise in the North Sea is caused by various sources due to human activities. This SCBA focuses on underwater noise caused, mitigated and prevented by following themes:

- Pile driving, specifically in the offshore wind industry.
- Seismic research on behalf of the oil and gas industry.
- Shipping.

Other sources of underwater noise, such as sonar and explosive, are not included in this analysis in order to enable an in-depth SCBA for the above selected themes.

3.7 Discounting

Costs and benefits of a project are rarely observed at exactly the same time. In order to compare the costs and the benefits their values are discounted to a base year. The idea behind discounting is that people have a preference for one euro today over a euro next year or in the distant future. A euro can be put in the bank, and then next year becomes one euro plus interest.

A euro's future value is being discounted at the discount rate. ‘Present value’ is another word for the value of (future) costs and benefits of the project in the base year. When the value of the future costs of the project is subtracted from the present value of future benefits, this is called the Net Present Value.

In the Netherlands, a discount rate of 5.5% is prescribed for SCBAs[17]; this can be interpreted as an annual return requirement set by the government on investments. This consists of a risk-free discount rate (2.5%) and a risk premium (3%). The idea behind the 2.5% risk-free discount rate is that the social return on public investment must be higher than the return that the government can get by investing in the capital market (opportunity cost of capital).

There are two exceptions to this general rule:

- If the perception exists that the risk rate for a specific project is higher or lower than 3%, it is permissible to calculate the risk rate project-specifically;
- Negative externalities that have an irreversible character should be discounted using a risk premium of 1.5% instead of 3%. Examples of such effects are: irreversible interventions in the landscape, loss of monuments, adverse impacts on biodiversity, CO2 and particulates.

For the SCBA for underwater noise, the lower risk premium could be applied for some effects. However, the effects that should be discounted against 4% instead of 5.5% are

[17] Currently, the value of the discount rate for SCBAs in the Netherlands is being re-assessed. The results of this assessment are not yet available. However, it is expected that the discount rate will be adjusted downwards, in line with macroeconomic developments. If the discount is adjusted downwards, this means that future values will be discounted at a lower rate. For this SCBA, it means that the outcomes will worsen (become more negative) due to the fact that both costs and benefits are spread equally over the time horizon.

not monetised in this study, because of the lack of valuation sources[18]. Therefore, the remaining effects (the ones that can be monetised) are discounted against 5.5%, as they are not externalities.

3.8 Overview of effects

The table below gives an overview of all effects that are investigated for the different activities.

Effect		Activities		
	Type of effect measurement	**Pile driving**	**Seismic surveys**	**Shipping**
Cost of noise mitigating measures / implementing policy	Monetised	✓	✓	✓
Avoided marine mammal disturbance days	Quantitative / qualitative	✓	✓	✓
Avoided non-workable days	Monetised	✓		
Avoided delayed start	Monetised	✓		
Decrease of cost price wind energy	Quantitative	✓		
Impact on achieving tender program offshore wind farms	Qualitative	✓		
Delay in executing surveys	Monetised		✓	
Hitting dry wells	Monetised		✓	
Travel time and travel costs ships	Qualitative			✓
Travel time goods	Qualitative			✓
Emissions	Qualitative			✓

Table 14 : Overview of effects investigated in the SCBA

[18] The main effect that cannot be monetised in this study are marine mammal disturbance days; is this would be possible, this effect could be discounted against a discount rate of 4%.

4 EFFECTS

In the paragraphs below, each effect (both costs and benefits) is described and where possible, the effects are quantified and/or monetised. The effect is always the difference between the relevant project alternatives and the baseline alternative as defined in chapter 2.

4.1 Pile driving

4.1.1 Costs of measures

Annex B gives an overview of possible noise mitigation measures. Costs for noise mitigating measures vary greatly between them, and can only be estimated correctly for each individual case (each individual wind farm). However, from the interviews it can be deduced that a typical set of mitigating measures costs between EUR 9 million and EUR 36 million for each wind farm. Such measures may include bubble curtains and sleeves. From the interviews and follow-up requests, the bandwidth of this number cannot be narrowed further.

For this SCBA, a bandwidth from EUR 9 million to 36 million is assumed to be relevant for one newly to be constructed wind farm[19], per year until 2023. As 2 wind farms per year are constructed, this figure needs to be double to be included in the SCBA.

In summary, and when the project alternative (no restriction period) is compared to the baseline alternative (restriction period), the costs of the measures can be presented as follows.

Effect	Alternative "No restriction period"
Costs of noise mitigating measures	18,000,000 – 72,000,000

Table 15 : Overview of costs (alternative compared with baseline alternative) in any reference year in the period 2016 – 2022 in EUR, price level January 2015.

4.1.2 Avoided non-workable days

Developers and contractors indicate it is difficult to estimate the costs of additional non-workable days caused by the current pile driving restriction period. When planning a new wind farm, weather scenarios are drawn up beforehand on which the planning of the installation is based. The best approach to estimate the costs of the pile driving restriction period for a contractor is to multiply the cost per installation day with the delta of the number of non-workable days in the restriction period versus non-restricted period.

The costs resulting from the pile driving restriction period mainly concern costs for using installation ships when they cannot be deployed. The availability of installation ships is critical. In the case pile driving activities have to take place in multiple years (with breaks in between), an installation ships becomes less employable.

[19] Here, an 'average' wind farm size is assumed. This cannot be narrowed down further as no specific information is available from the interviews.

An installation ship would not be available for another project in between, which in turn leads to higher prices of a ship. Autumn is known for stormy weather, which increases the chance of adverse weather and delays in construction.

The costs of non-availability of the installation team on an installation ship (manpower) are estimated at EUR 200,000 per day (based on interviews with contractors). The costs for leasing an installation ship by the developer from the contractor are estimated at EUR 50,000 per day on average (based on interviews with contractors). In total, the costs of a non-workable day for a contractor are EUR 250,000 per installation day on average. However, these total costs per installation per day differ for each wind farm location or selected installation process of a contractor, and range between EUR 100,000 to EUR 350,000 per day. In case of a large offshore wind farm a contractor may have to deploy two installation ships to be able to perform all pile driving activities within one compact time period. In this case the costs for an installation day are doubled to EUR 500,000 on average.

Under the assumption a year consists of 360 days, 180 days (half a year) are available for both the pile driving and pile driving restricted period. Based on interviews with contractors it is estimated that during the 180 days available for pile driving (1 July until 31 December) about 60 days are non-workable due to weather conditions. For the 180 days during the pile driving restricted period (1 January until 30 June), it is estimated there would be 30 days non-workable in case pile driving would be permitted in this period.

In the baseline alternative, in which there is a restriction period, the total number of workable days equals 180 -/- 60 = 120.
In the project alternative, in which there is no restriction period, the total number of workable days equals 360 -/- 60 -/- 30 = 270.
However, since the demand side does not increase (two wind farms will be constructed per year), the installation teams will not increase their production, but rather work in a more favourable season. Therefore, the complete gain of 270 -/- 120 = 150 days cannot be taken into account. Rather, the installation team will do the same amount of work in a better season, thereby incurring lower cost due to a decreased number of non-workable days. To be precise: the gain will be 60 -/- 30 = 30 avoided non-workable days.

A gain of 30 non-workable days per wind farm per year, times two wind farms, times the cost estimate of EUR 250,000 per day, are multiplied, yielding a benefit of EUR 15,000,000 per year. In other words, a potential cost saving of EUR 15 million could be achieved by the developer in case pile driving has no restriction period.

Effect	Alternative “No restriction period”
Avoided non-workable days	15,000,000

Table 16 : Overview of effects (alternative compared with baseline alternative) in any reference year in the period 2016 – 2022 in EUR, price level January 2015.

4.1.3 Marine mammal disturbance days

As explained in chapter 3, an important effect in this SCBA is the change in marine mammal disturbance days. This effect is defined as the benefit of having less marine mammal disturbance days in case of alternative measures compared to measures in the baseline alternative. A marine mammal disturbance day is the product of the number of disturbed marine mammals (in this case harbour porpoises) per day of disturbance by piling (or seismic surveys) and of the number of days at which the disturbance takes place (keeping in mind the difference in seasons and the duration of the disturbance per disturbance day). Marine mammal disturbance days are used as input for a specific population model (Interim PCoD) to calculate the population reduction in different scenarios. For more details see TNO (2015).

In the Netherlands a pile driving restriction in the months January to July is obligatory in current policy. This pile driving restriction was implemented in 2010. At the time of implementation it became evident that underwater noise produced by human activities could negatively impact the marine environment. By implementing a pile driving restriction in the spring a higher number of disturbed harbour porpoises is avoided as the density of harbour porpoises is larger in the spring compared to the fall on the Dutch EEZ (Commissie M.E.R., 2012).

The ecological impact of pile driving can be either expressed in affected area in km^2 or the number of 'animal disturbance days'. This is a measure used to investigate the cumulative impact of underwater noise on marine mammals described by TNO (2015). The duration of disturbance during construction can vary. For a realistic scenario one impulse day is considered to be equivalent to one disturbance day of 24 hours. The total number of impulse days is the number of days when an impulsive noise is produced due to pile driving or seismic survey. Usually the hammering of a monopile doesn't take a whole day but only 4 hours. For the calculations, however every impulse day at which piling take place (regardless of hammering time) counts as one disturbance day. This is because harbour porpoises can be disturbed for a longer time than the actual hammering time (see TNO, 2015).

The TNO (2015) model has made several assumptions:

- All wind turbines have a capacity of 6 MW.
- The number of turbines per park is calculated by dividing the maximum capacity by 6 MW.
- In all cases the foundation is considered to be the same (monopile, tripod or jacket and every 48 hours construction takes place). One pile driving day is always followed by one day without pile driving to allow time for placing of the construction ship.

TNO (2015) has calculated several scenarios for pile driving of wind farm foundations and seismic surveys in The Netherland and the neighbouring countries with mammal disturbance days as an output. For more details see TNO (2015). The most relevant scenarios for this SCBA dealing with piling activities in The Netherlands are:

A. Only Dutch wind farms scenario A: 2x construction wind farms in the spring
B. Only Dutch wind farms scenario B: 2 wind farms in spring with a noise threshold of 160 dB re 1 $\mu Pa^2 s$ SEL at 750 meters

C. Only Dutch wind farms scenario C: 1 wind farm in spring and 1 in fall
D. Only Dutch wind farms scenario D: 2 wind farms in fall.

As no more up-to-date information is available, the data from TNO have been taken into account in this SCBA, specifically focusing on scenarios B (Alternative "No restriction period"' in this study), and D (baseline alternative in this study). The number of disturbed harbour porpoise days in scenario B and D is 203,668 and 802,261 days, respectively. In the table below a summary is given of the impact, expressed in harbour porpoise disturbance days for the project alternative considered in this SCBA, compared with the baseline alternative. The results from TNO (2015) show that the harbour porpoise disturbance days are significantly less when pile driving in the fall, compared to pile driving in the spring. The results also show that a noise limit of 160 dB re 1 μPa^{2}s (SEL at 750 m) significantly decreases the number of harbour porpoise disturbance days overall. The TNO study (2015) describes the effects on population reduction for the different scenarios.

When this is translated to a SCBA table, the figures as per the table below are obtained. As underwater noise is now diminished, the disturbance days decrease from 802,261 to 203,668 over the period 2016 – 2022. Thus, the decrease has a value of 598,593 days over this period. For SCBA purposes, this total amount is expressed per year, in order to ensure comparability between the effects.

Unfortunately, as no research has been conducted to the value of harbour porpoise disturbance days, this effect cannot be monetised at the moment. It is recommended that this additional research is conducted.

Effect	Alternative "No restriction period"
Avoided marine mammal disturbance days	85,513

Table 17 : Overview of effects (alternative compared with baseline alternative) in any reference year in the period 2016 – 2022 in number of days.

4.1.4 Delayed start of offshore wind farm operations

If a seasonal pile driving restriction applies, this can have an impact on the start of operations of offshore wind farms. Even though the planning process will take into account the restriction, due to exogenous factors the construction process may be delayed beyond the restriction cut-off date. Even a delay of just a few days beyond the restriction cut-off date would cause the project to be delayed for the complete restriction period. In other words, if the restriction applies to a 6-month period, this would mean a delay for the start of operations of a wind farm of 6 months. The lost profits as a consequence of the delay form a welfare effect. As mentioned before different mitigation measures cause different delays. The effect of different measures could not be investigated as part of this study due to lack of information. However, a general approach has been followed to obtain an estimate.

The valuation of the effect is immediate: as the power produced by the wind farm is sold on the energy forward market, and the farm would not be able to produce due to the restriction, the loss to the farm can be computed as the number of days of no production x daily production x contractual forward power tariff (or energy spot price) x profit margin.

Whereas the actual costs depend on multiple unknown factors (number of delays, number of wind farms, production volume of wind farms, agreed forward tariff, profit margin), the cost for a typical delayed opening of a wind farm could be

180 days x 350MW x 10 full load hours x EUR 50 / MWh x 10% profit margin[20] = EUR 3,150,000.

It is assumed that two new wind farms are opened each year between 2015 and 2023, and that 25% of the wind farms will be delayed such, that they will suffer from the restriction period. Therefore, the effect of EUR 3,150,000 is multiplied by two (two farms per year) and multiplied by 25% (25% of the farms is delayed). This yields:

EUR 3,150,000 x 2 x 25% = EUR 1,575,000 per year.

The annualised effect is presented in the table below.

Effect	Alternative “No restriction period”
Avoided delayed start	1,575,000

Table 18 : Overview of effects (alternative compared with baseline alternative) for any reference year in the period 2016 - 2022 in EUR, price level January 2015.

4.1.5 Effect on cost price of offshore wind energy

Alternative pile driving methods due to restrictions lead to an indirect effect, namely a price alteration of the cost price of offshore wind energy. The reasoning is as follows: if the restrictions cause construction firms to use alternative (costlier) pile driving methods, this will make the overall construction of wind farms more expensive. This will be reflected in a price change of wind energy prices.

The valuation of this effect depends on the costs for pile driving as part of the overall construction costs. According to EWEA, the construction of the foundation of offshore wind farms equals approximately 7% of the total construction costs. If an alternative pile driving method would be 10% more expensive than the preferred method, this could lead to an increase of construction costs, and therefore, of the offshore wind energy price, of 0.7%. it must be stated that this increase should be regarded as a maximum, as the increased costs of alternative pile driving methods may be mitigated (for example due to risk mitigation measures surrounding the alternative pile driving method).

Effect	Alternative “No restriction period”
Price decrease of cost price wind energy	0.7%

Table 19 : Overview of effects (alternative compared with baseline alternative) for any reference year in the period 2016 - 2022 in a percentage.

[20] 10 full load hours are based on a RHDHV expert opinion, EUR 50 / MWH is an average spot price for base load power, 10% profit has been estimated by RHDHV.

4.1.6 Effect on tender program of offshore wind farms

Based on the tender program 2015 – 2019, 700 MW of offshore wind energy will be realised every year. This corresponds with approximately 115 to 175 turbines and associated monopiles, based on an estimated turbine capacity of 4 to 6 MW. Given that driving one monopile takes two days, a 700 MW wind farm requires 233 days. In the baseline alternative only 120 workable days are available per calendar year, whereas in the Alternative “No restriction period”, 270 workable days are available in one calendar year. Clearly, removing the piling restriction period has a positive impact on the likelihood that projects under the tender program offshore wind will be realised on time; in fact, realising 2 wind parks per year while the restriction period is in place does not seem feasible.

Offshore wind energy is an important contributor to achieve the target of 14% renewable energy by 2020. This target has been agreed with the European Union. In the worst case scenario the European Union is able to impose a penalty for not realising this target. This worst case scenario may arise for the Netherlands in case the current pile driving restriction period leads to serious time delay compared to the agreed tender program 2015 – 2019. It is possible that the EC would impose penalties in case national targets on renewable energy are not met.

As it cannot be impartially established whether or not the alternatives would actually be the cause of penalties being imposed on the Netherlands, this effect cannot be measured or monetised. However, something can be said about the direction of the effect. As more measures are introduced that benefit the underwater noise situation, this may negatively impact the possibilities to achieve the tender program on time, as implementing the measures effectively will take time.

Overall, the expected strong positive impact on the feasibility of realising two wind farms in one year, versus the moderately negative impact of timely implementing measures to mitigate or prevent underwater noise, results in a moderately positive assessment of this effect.

Effect	Alternative “No restriction period”
Impact on achieving tender program offshore wind farms	0/+

Table 20 : Overview of effects (alternative compared with baseline alternative) for any reference year in the period 2016 – 2022.

4.2 Seismic research

4.2.1 Costs of measures

For the alternative “Procedural measures” of seismic research (introducing a seasonal restriction) there are no relevant direct costs, as implementing this policy in itself would not bear relevant costs.

Moreover, the alternative "Fewer surveys" is also cost-free (implementing the policy is cost-free)[21]. This is expressed in the SCBA table below.

Effect	Alternative "Procedural measures"	Alternative "Fewer surveys"
Costs for implementing policy	0	0

Table 21 : Overview of costs (alternatives compared with baseline alternative) in EUR, price level January 2015.

4.2.2 Marine mammal disturbance days

For pile driving the ecological impact of mitigation measures was expressed in the number of harbour porpoise disturbance days. For seismic surveys, TNO (2015) has calculated a scenario for seismic surveys for all international activities on the North Sea. It is impossible to extract only the data for the Dutch EEZ; therefore a qualitative estimation of effects on marine mammal disturbance days has been made. The study by TNO (2015) however, concluded that the international cumulative impact of underwater noise produced by seismic surveys can be equivalent to international cumulative impact of underwater noise produced during pile driving[22].

Effect	Alternative "Procedural measures"	Alternative "Fewer surveys"
Avoided marine mammal disturbance days	+	++

Table 22 : Overview of effects (alternatives compared with baseline alternative) for the period 2015 – 2044 in numbers.

4.2.3 Delay in executing surveys

In the alternative "Procedural measures", an introduction of a seasonal restriction, the period from 1 January until 1 July of each year would be restricted for seismic research. This entails that seismic research can only be conducted in the remaining months. As a consequence, more research will have to be done in the autumn months in which the weather is less favourable (plus, materials may be more costly). In turn, it is expected that the research will be delayed.

For the SCBA, it is assumed that the normal period of research of 8 weeks is extended by 50%. The rental of a suitable ship costs EUR 225,000 per day approximately[23]. The additional costs of the delay therefore amount to

[21] It could be argued that there are in fact benefits (avoided costs) resulting from less seismic surveys. While this is undeniably a cost saving in itself, we deem this effect not to be very significant vis-à-vis the benefits of seismic surveys (the oil and gas industry would otherwise decide to do so, also without a seasonal restriction).

[22] The costs and possibilities for mitigation measures for pile driving and seismic surveys are however of a different level. Mitigation for noise produced by seismic surveys is much more difficult.

[23] As derived from the interviews.

50% x 8 weeks x 7 days x EUR 225,000 / day = EUR 6,300,000.

It is assumed that 2 studies per year are conducted, which yields a total effect of EUR 12,600,000 annually. This is reflected in the table below.

Effect	Alternative "Procedural measures"	Alternative "Fewer surveys"
Delay in executing surveys	- 12,600,000	0

Table 23 : Overview of effects (alternatives compared with baseline alternative) for any reference year in the period 2015 – 2044 in EUR, price level January 2015.

4.2.4 Hitting dry wells

In the alternative "Fewer surveys", reducing the number of surveys by reprocessing old data, the probability of misinterpreting the data is a relevant effect. The consequence of this will be that the number of times a dry well is hit increases.

In the SCBA, it is assumed that the probability of hitting a dry well increases by 25%[24]. Currently, based on analysis over the period 1972 – 2013, the probability of hitting a dry well equals 25%[25]. Approximately 40 drillings per year take place. The costs of drilling for a dry well amount to EUR 30,000,000. Thus, the annual additional costs resulting from an increased amount of hitting dry wells are expressed as

25% increase x 25% probability x 40 times / year of hitting a dry well x EUR 30,000,000 = EUR 75,000,000.

This result is included in the table below.

Effect	Alternative "Procedural measures"	Alternative "Fewer surveys"
Hitting dry wells	0	- 75,000,000

Table 24 : Overview of effects (alternatives compared with baseline alternative) for any reference year in the period 2015 - 2044 in EUR, price level January 2015.

4.3 Shipping

4.3.1 Important principles

Very little is known about the benefits, costs, direct and indirect effects of measures for shipping. A lot of answers will be provided by the EU SONIC project, due to deliver its results in October 2015. As a result, in this study it is not possible to quantify, let alone monetise, the relevant effects. In executing the study it was attempted to create a bandwidth around the results as a minimum, but this proved to be impossible, as the

[24] Expert opinion RHDHV.
[25] Data from http://www.nlog.nl/nl/activity/activity.html (10 Feb 2015)

interviews with the activity representatives did not yield any relevant (quantified) information.

An important assumption underlies the assessment of effects in this chapter regarding shipping effects: the market for shipping is currently in equilibrium, i.e. any change or restriction will have a negative economic effect as it will distort the equilibrium market situation[26]. For example: an imposed lower speed limit on shipping may lead to decreased fuel usage, but will lead to longer delivery times. One may reason that the net effect of these two effects is either unknown, zero, negative or positive. However, coming from an equilibrium situation, the net effect of these two effects can only be negative, because the ship owner would be forced out of his equilibrium state: if he wanted to reduce speed because that would be more efficient, he could make also that decision without new restrictions being imposed on him (i.e. without the project intervention).

4.3.2 Costs of measures

In the alternative “Procedural measures”, speed reduction, there are no immediate costs. In the alternative “Technical measures”, adjustments of propellers, hull form and design are high-impact measures with associated high costs (possibly millions of euros per ship) depending on the type and size of the ship. The costs of these adjustments cannot be estimated at the moment upon asking the activity representatives: currently the complete Dutch registered fleet does not qualify to the IMO guidelines (interview Marin). Adjustments to the fleet as a result of the implementation of the IMO guidelines are expected to be very costly.

Effect	Alternative “Procedural measures”	Alternative “Technical measures”
Costs for implementing policy	0	PM

Table 25 : Overview of costs (alternatives compared with baseline alternative) in EUR, price level January 2015.

4.3.3 Marine mammal disturbance days

Due to measures taken in the project alternatives, the disturbance for marine species will be less. In the case of shipping, fish are probably more sensitive to ambient underwater noise than marine mammals. There is however no quantitative (and very little quantitative) information available for fish. Therefore the marine mammal disturbance days are used as this is the best available data. The marine mammal disturbance days will be reduced. However, no research is available to the extent to which this would happen. Therefore, this effect cannot be quantified at the moment. The table below assesses the effect qualitatively. It is expected that technical measures will have a greater impact than solely a speed reduction.

[26] Based on expert judgement

Effect	Alternative "Procedural measures"	Alternative "Technical measures"
Avoided marine mammal disturbance days	+	++

Table 26 : Overview of effects (alternatives compared with baseline alternative) for any reference year in the period 2015 - 2039.

4.3.4 Travel time and costs on ships and goods

The effects on shipping of speed reduction and/or ship adaptations are threefold. These effects are described below.

Travel time and costs for ships
Imposing a speed reduction would lead to a longer travel time; this is a negative welfare effect. Even though the fuel usage would decrease, the net effect of these would be negative in a current equilibrium situation.

However, installing adapted propellers, isolation of machinery or an amended hull design may benefit the travel time as well as fuel usage. The net effect in this alternative would probably be positive[27].

Travel time goods
Travel time for goods is a different welfare effects from the travel time for ships. The reason for this lies in the characteristics of the goods differing from those of the ships. Goods have a different value and a different time dependency. However, in general it can be stated that a speed reduction leads to longer delivery times which will have a negative effect on the value of the goods.

However, installing adapted propellers, isolation of machinery or an amended hull design will probably have no effect[28].

For all these effects, the time value of ships, time value of goods as well as the travel costs are available in literature. However, as the extent of the policy is unknown at the moment, only the direction of the effects can be estimated; it cannot be quantified or monetised. The table below summarises the effects for shipping.

Effect	Alternative "Procedural measures"	Alternative "Technical measures"
Travel time and travel costs ships	-	+
Travel time goods	-	0

Table 27 : Overview of effects (alternatives compared with baseline alternative) for any reference year in the period 2015 - 2039.

[27] Based on expert judgement
[28] ibid

4.3.5 Emissions

A clear positive effect of an imposed speed reduction is the decrease of emissions. This effect would probably also play a role when installing adapted propellers, isolation of machinery or an amended hull design.

Again, as the size of the effect cannot be measured (the number of ships is unknown, as well as the extent to which the measures would be implemented), it can only be assessed qualitatively.

Effect	Alternative "Procedural measures"	Alternative "Technical measures"
Emissions	+	+

Table 28 : Overview of effects (alternatives compared with baseline alternative) for any reference year in the period 2015 - 2039.

5 RESULTS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Outcomes

5.1.1 Pile driving

The table below summarises all costs and effects of the project alternatives compared against the baseline alternative in any given year of the horizon period.

Effect	Unit	Alternative “No restriction period”
Avoided non-workable days	EUR	15,000,000
Cost of noise mitigating measures	EUR	- 18,000,000 to -72,000,000
Avoided marine mammal disturbance days	Number	85,513
Avoided delayed start	EUR	1,575,000
Price decrease of cost price wind energy	%	0.7%
Impact on achieving tender program offshore wind farms	Qualitative	0/+

Table 29 : Summary of effects in any reference year in the period 2016 – 2022, prices are in EUR, price level January 2015.

The net present value for costs and benefits has also been calculated, for the effects that could be monetised. However, as one of the most important effects (avoided marine mammal disturbance days) could not be monetised, the NPV is of limited value. For the alternative “No restriction period” of the activity pile driving, the NPV is between -/- EUR 8 million and -/- EUR 314 million (both +PM and depending on costs of noise mitigating measures).

From the table above, it can be derived that for the effects that can be monetised, the benefits do not outweigh the additional costs that are required to introduce sufficient measures. Even though the number of non-workable days and the probability of a delayed start have decreased, the costs of implementing the measures are very high.

In an additional analysis, the break-even point has been investigated. The break-even point between costs and benefits (the net present value must then be zero) lies at EUR 16.6 million (for two wind farms). This means that, if the implementation costs for the measures can be reduced to approximately EUR 8 million per wind farm, the NPV would be positive and the project would be socioeconomically viable. Since marine mammal disturbance days cannot be monetised, this result would improve even further if those could be monetised.

5.1.2 Seismic research

The table below summarises all costs and effects of the project alternatives compared against the baseline alternative in any given year of the horizon period.

Effect	Unit	Alternative “Procedural measures”	Alternative “Fewer surveys”
Costs for implementing policy	EUR	0	0
Avoided marine mammal disturbance days	Number	+	++
Delay in executing surveys	EUR	- 12,600,000	0
Hitting dry wells	EUR	0	- 75,000,000

Table 30 : Summary of effects in any reference year between 2015 and 2044, prices are in EUR, price level January 2015.

The net present value for costs and benefits has also been calculated, for the effects that could be monetised. However, as one of the most important effects (avoided marine mammal disturbance days) could not be monetised, the NPV is of limited value. For the alternative “Procedural measures” of the activity seismic research, the NPV is -/- EUR 190 million.

From the summarising table and the NPV calculation, it can be concluded that even though the measures in both alternatives do not bear immediate additional costs, the negative impact is very significant. In the alternative “Fewer surveys”, reduced quality of research due to reprocessing of existing data results in more dry wells being hit, which leads to an NPV of over -/- EUR 1.1 billion over a period of 30 years.

However, the number of marine mammal disturbance days that is avoided due to the measures is also significant: even though it cannot be estimated at this stage, the number of avoided marine mammal disturbance days is positive in both alternatives.

5.1.3 Shipping

The table below summarises all costs and effects of the project alternatives compared against the baseline alternative in any given year of the time horizon.

Unfortunately, very little is known about the benefits, costs, direct and indirect effects of measures for shipping. As a result, in this study it is not possible to quantify, let alone monetise, the relevant effects. In executing the study it was attempted to create a bandwidth around the results as a minimum, but this proved to be impossible, as the interviews with the activity representatives did not yield any relevant (quantified) information.

Effect	Unit	Alternative “Procedural measures”	Alternative “Technical measures”
Costs for implementing policy	EUR	0	PM
Avoided marine mammal disturbance days	Qualitative	+	++
Travel time and travel costs ships	Qualitative	-	+
Travel time goods	Qualitative	-	0
Emissions	Qualitative	+	+

Table 31 : Summary of effects in any reference year between 2015 and 2039.

From the table, it can be derived that imposing a lower speed limit has both positive and negative effects, where the costs of implementing the policy would be close to zero. Marine mammal disturbance days as well as emissions are positively impacted, whereas the travel time and costs for both ships and goods will be impacted negatively. It cannot be established what the resulting effect is. It is suggested that this research is done for specific areas and/or specific fleets.

If technical measures are introduced, the expected positive effect on marine mammal disturbance days is greater, whereas the other effects are also impacted positively. Therefore, the net benefits are clearly positive. However, the costs of such operation are at the moment fully unknown. Considering the size and impact of the measures on fleets, it can only be estimated that the costs will be (very) high. It is strongly recommended that more research in this field is executed.

5.2 Notes and remarks

The following notes and remarks must be observed when interpreting the results of this study:

- 'Marine mammal disturbance days' acts as an index number for the measurement of ecological effects in the SCBA. However, at present this index cannot be monetised, which makes comparison between alternatives and between effects difficult. It is recommended that research is done how to value this aspect.
- For pile driving specifically, it would be very insightful if more information would be available about the costs of individual measures, as this would enable the comparison for these measures in terms of cost-effectiveness.
- As explained in this report, the measures for the shipping sector cannot be monetised yet (the costs are yet unknown; no useful could be derived from the interviews), it is advised that this topic is researched further. Also, a separate CBA for specific measures and specific fleets would be useful, as quantified and, where possible monetised, results can be gathered to bring focus to the discussion.
- As for pile driving, the measures that need to be introduced instead of a seasonal restriction are very expensive, it is useful to further detail these costs and to investigate whether these can be reduced.

It is the view of the authors of this report that the findings from this study are useful for several purposes. First of all, the fact finding activities that were undertaken form an important part of the project, which results in bringing together data on costs of measures to prevent and mitigate underwater noise. This type of data had not been collected and presented in this way before. At the same time, this is also a first step to compare the cost effectiveness of measures aimed at different activities (i.e. pile driving, seismic surveys and shipping), even when the costs for individual measures could not be estimated. The second contribution of these findings lies in the monetised values of at least a part of the effects. Whereas one of the main goals of any measure, decreasing marine mammal disturbance, cannot currently be monetised, at least part of the costs and benefits could be monetised, making the outcomes comparable. This means that when in the future marine mammal disturbance days can be monetised as a result of further research, a full comparison on SCBA level will be possible (it is suggested that an SCBA on project level is executed). But even when not considering the ecological benefits, a main finding is that bringing the costs of measures down to a level calculated in this study (approximately EUR 8 million per wind farm), means that on a purely monetary basis alone, the benefits equal the costs of mitigating measures (compared to the restriction period). It is advised to investigate whether location specific packages of measures under EUR 8 million are feasible for wind farms.

APPENDIX A – UNDERWATER NOISE EFFECTS ON MARINE SPECIES

Underwater noise is known to impact different marine species including marine mammals, fish species, birds, etc. Although birds are only submerged for a small period to find fish, loud noise sources may influence their behaviour. This aspect remains to be investigated and no information on effects of fish eating birds is present. Effects on birds will not be described further in this document. This appendix does describe the effects of noise on marine mammals and fishes.
There are two categories of noise: (1) short duration noise or impulsive noise (e.g. impulsive such as from seismic surveys and pile driving for wind farms and platforms, as well as explosions) or (2) ambient noise (such as from dredging, shipping and energy installations) affecting organisms in different ways. From both categories the effects are described below.

Marine Mammals

Studies on effects of underwater noise on marine species define different levels of noise impact. Noise can affect animals from a low level, at which it is heard but doesn't lead to a reaction, to a more extreme level, at which it physically damages the animals or even causes death. Van der Graaf (2012) has divided the effects of underwater noise on marine mammals according to sound pressure and frequency in different categories. The division is for all animals the same, only the limit depends on the species and the situation:

- Hearing zone: all noise that can be heard by an individual. Background noise and the sensitivity of the hearing apparatus are important. All noises, even those at which animals do not react are included in this category.
- Reaction: this is every noise for which animals show a reaction in their behaviour. Reactions can be small (distraction) or (curious) animals can be attracted to noise. The strongest reaction is that the animals leave the area. Also a (severe) discomfort zone (see below) is part of this category.
- Masking: Masking occurs when anthropogenic noise interferes with the sounds produced by animals (comparable in frequency and noise amplitude), or those of their prey or predators. Hereby communication or foraging skills can be disturbed.
- Hearing damage: occurs when the noise is so strong that temporary threshold shift (TTS) or permanent threshold shift (PTS) can occur, causing hearing damage of marine mammals. The spectrum of the noise levels is important for this category.
- Other physical or physiological damage or death: these are noises that are so strong that irreversible damage occurs of organs other than the hearing apparatus and that can disturb functions or even lead to death.

Ambient noise

Little information on ecological effects of ambient sound on marine species is available. Ambient sound mostly produces low frequency noise. Fish are the most sensitive for this type of sound than marine mammals as they use lower frequencies to communicate. However, some effects on marine mammals have been observed in the field (Southall et al., 2007) due to shipping and drilling. The study compared results of studies that looked at the effects on marine mammals and described observations, individual movements and behavioural patterns (authors in Southall et al. 2007). Green (2004) described that some whales rely on low-frequency for communication over large distances; these frequencies are the same as those produced by shipping. It is documented that icebreakers cause avoidance reactions in narwhales, belugas and walruses. Some scientists are concerned that shipping may have population impacts on these species. Long-term chronic noise has the potential for permanent damage on the hearing system of marine mammals. Masking, changes in behaviour and habitat displacement are effects that are mentioned as most urgent for marine mammals concerning shipping on a global scale. A study on the effects of Trailer Suction Hopper Dredging vessels (TSHD) on the harbour seal show that the noise produced by a TSHD is audible to a harbour seal over a range of approximately 35 Hz to 40 kHz (Nedwel et al., 2014). There is a peak in sensitivity between 200 Hz to 10 kHz. Several experimental designs are proposed to investigate (ecological) effects and an overview of several future investigations on effects on pinnipeds are described in the paper. The authors conclude that temporary behavioural responses (avoidance and disturbance) do not appear to have substantial adverse effects on pinniped populations.

Impulsive noise

Most information is available on effects of impulsive sound on marine animals. Studies have shown that marine mammals are most sensitive to underwater noise produced by impulsive sound compared to other marine species. There are various marine mammals such as minke whales, bottlenose dolphins and white-sided dolphins that can be found occasionally in the Dutch North Sea (van der Akker & Veen, 2013). However, the most frequent occurring marine mammals include the harbour porpoise, harbour seal and grey seal. In this study we focus on the most common species. Marine mammals can be classified in different categories based on noise sensitivity for impulsive noise. Southall (2007) identifies three categories: low frequency, medium frequency and high frequency hearing marine mammals. Harbour porpoises and seals belong to the group of cetaceans which are considered “high frequency mammals” meaning that these species are mostly sensitive to high frequency sounds. This study is specifically applicable for the North Sea. Elsewhere the impact of the underwater noise on the marine environment may be different because other species, with a different sensitivity for sound, reside in those locations, and thus other mitigation measures might be necessary.

Effects with consequences for disturbance, damage and masking can have influence on individual levels, but also on population levels. The ecological effects are different depending on the type of noise produced. For impulsive sound, it is thought that the effect on communication is low because the energy produced by airguns and pile driving reduces significantly at high frequencies (those used for echolocation) and thus probably doesn’t lead to interference and negative effects for marine mammals. However, the real effects are still unknown and impulsive noise can still have large effects on behaviour (avoidance) and even damage or death when the sound source is to nearby.

The paragraphs below will focus specifically on impulsive sound and its effects on harbour porpoise and harbour seal.

Harbour porpoise and impulsive sound

Hearing
The harbour porpoise has a large frequency range from 200 Hz to 180 kHz (Southall et al., 2009). The frequency range is demonstrated by the harbour porpoise audiogram shown in the figure below. The harbour porpoise uses high frequency noise for echolocation. It uses noise to find prey and detect predators, but also to communicate.

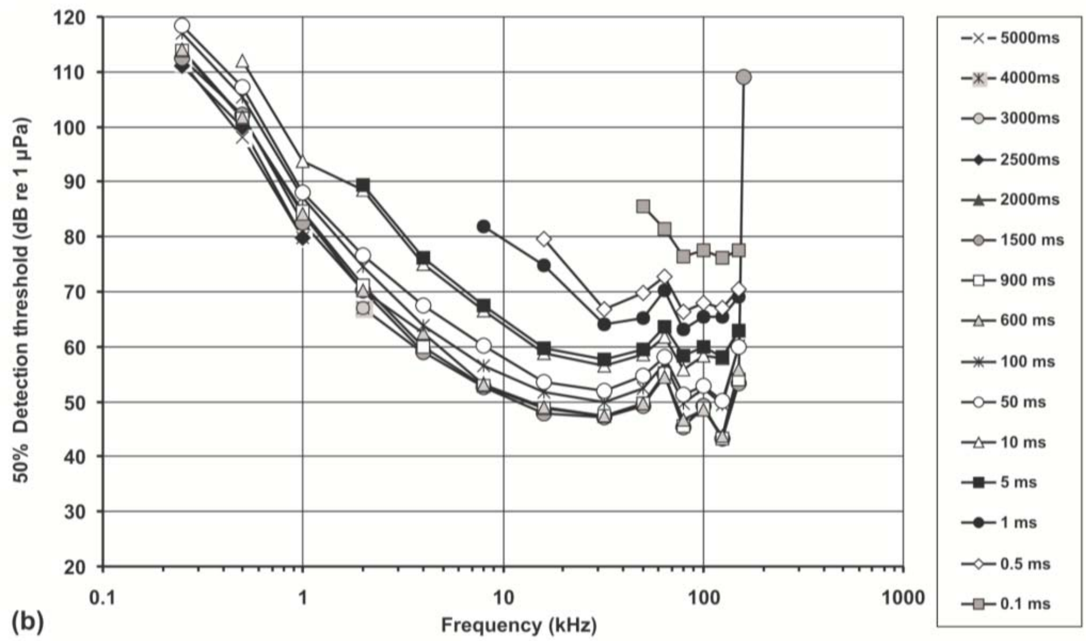


Figure 10 : Audiogram of a harbour porpoise for almost all signals at different signalling (Kastelein et al., 2010 b in TNO, 2015).

When sound levels exceed the hearing threshold, depending on the intensity level, it can cause avoidance, TTS and even PTS shift. The SEL at which these levels of disturbance occur are shown in the table below (data from TNO (2015).

Species	Type of effect	Threshold value	Literature
Harbour porpoise	Avoidance	SEL_1 > 140 dB re 1 μPa^{2}s/ 136 dB re 1 μPa^{2}s	TNO (2015) / Kastelein et al. 2011
	TTS-onset	SEL_{cum} > 164 dB re 1 μPa^{2}s	Lucke et al. 2009
	TTS-1 hour	SEL_{cum} > 169 dB re 1 μPa^{2}s	TTS-onset + 5 dB
	PTS-onset	SEL_{cum} > 179 dB re 1 μPa^{2}s	TTS-onset + 15 dB
Harbour seal	Avoidance	$SEL_{1,w}$ > 145 dB re 1 μPa^{2}s	Kastelein et al. 2011
	TTS-onset	$SEL_{cum,w}$ > 171 dB re 1 μPa^{2}s	PTS-onset – 15 dB
	TTS-1 hour	$SEL_{cum,w}$ > 176 dB re 1 μPa^{2}s	TTS-onset + 5 dB
	PTS-onset	$SEL_{cum,w}$ > 186 dB re 1 μPa^{2}s	Southall et al. 2007

Table 32: Calculated threshold values that have a certain impact on harbour porpoises and harbour seals. Sound exposure level (SEL) is proportional to the total energy of a signal expressed in dB re 1 μPa^{2}s. Source: Southall, 2007. SEL_1 = noise level of one single strike; SEL_{cum} = noise level perceived by a marine mammal after pile driving activity of one pile thus multiple strikes; $SEL_{1\ +\ cum,w}$ = M-weighted SEL for seals in water, see Southall, 2007.

Vulnerable period of the harbour porpoise

The effect of underwater noise on the population of marine mammals such as the harbour porpoise can differ throughout the year as there is a seasonal difference in the number of harbour porpoises that reside on the Dutch EEZ (see figure below, Geelhoed et al., 2013, Geelhoed et al., 2014a en Geelhoed et al., 2014b). The impact can therefore in a certain period have more impact on individuals or even populations depending on the season. During certain periods harbour porpoises are more vulnerable to disturbance than others:

- In May, June and July the harbour porpoise young are born and nursed especially in areas northeast of the Dutch Wadden islands. There are indications that they also are present along the Dutch coast. Underwater noise is enhancing the chance that mothers and calves are being separated from each other.
- According to aerial surveys the density of harbour porpoise is highest in March and the density decreases in July and even more in October/ November (see figure below).This means that on the Dutch EEZ, underwater noise has the largest impact on the population in spring.

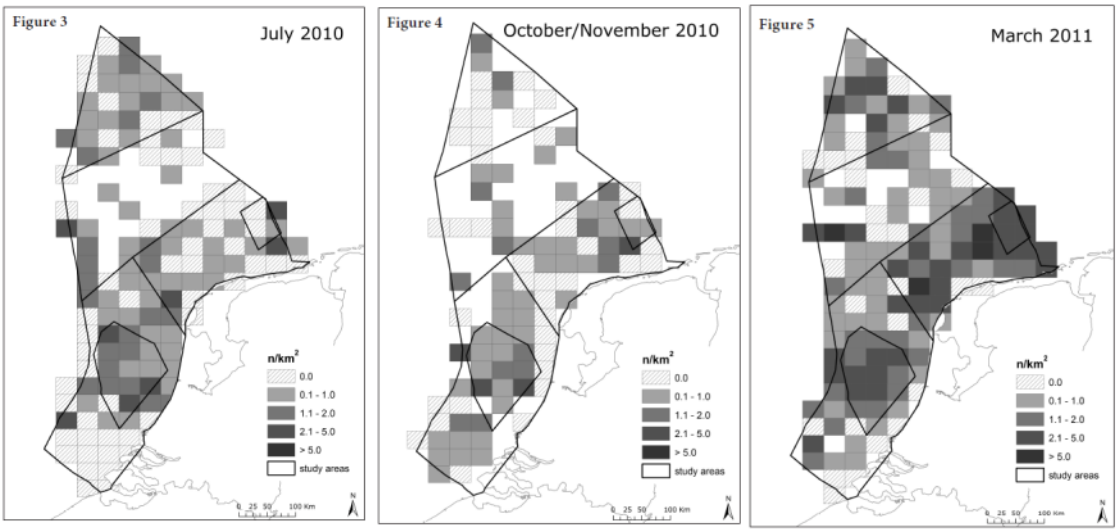


Figure 11 : Airplane survey of the distribution of harbour porpoise in July 2010, October/November 2010 and March 2011 on the Dutch EEZ (Geelhoed, 2013).

Harbour seal and impulsive sound

Hearing

Seals also use sound to forage, to find and detect prey. Seals are pinnipeds and have a different and smaller frequency range compared to harbour porpoises. However pinnipeds are also considered to be high frequency marine mammals. Their hearing frequency ranges from 75 Hz till 75 kHz. Figure below shows an audiogram for harbour seals demonstrating their frequency range and sound threshold. This is a slightly smaller range compared to harbour porpoises and they are less capable of hearing very high frequency sounds. There are studies that also show that seals are less vulnerable to underwater noise than harbour porpoises (Kastelein et al. 2011). The noise threshold levels for avoidance and TTS- and PTS onset result in higher sound exposure levels for seals (see figure 12).

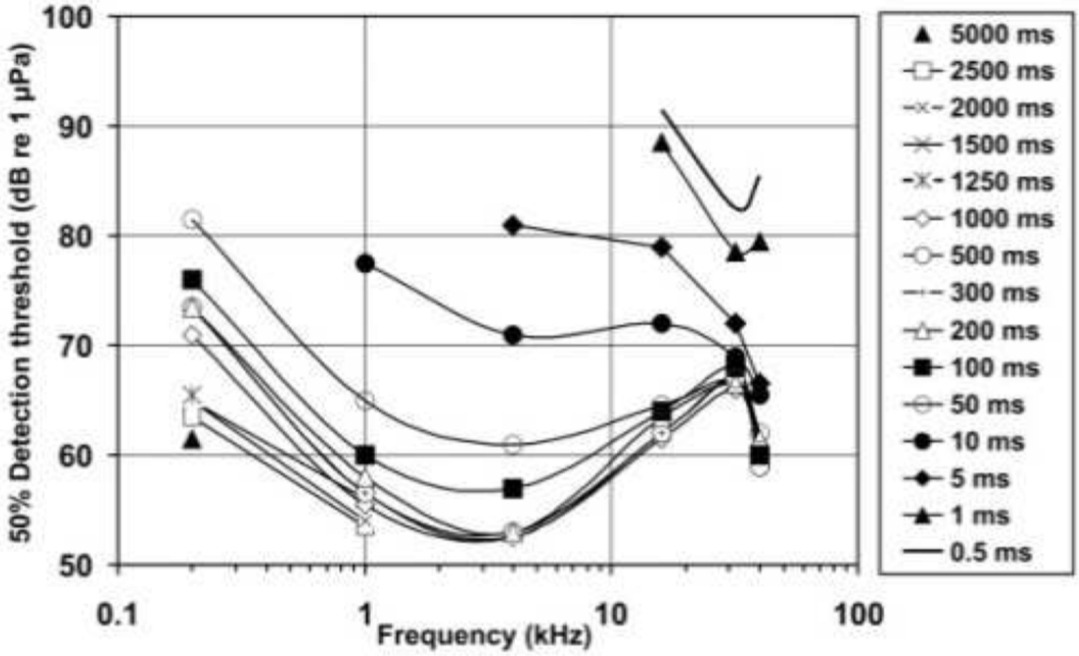


Figure 12 : Audiogram of the harbour seal for (almost) all signals at different signalling (Kastelein et al. 2010a, in TNO, 2015).

Vulnerable period seals

The harbour seal and grey seal are present throughout the year along the Dutch coast. They are mostly concentrated in shallow waters near the shore (see figure below). However, the harbour seal is (rather) linked to the Dutch coastal waters and make short travels to forage, while grey seals may make longer travels to forage (occasionally between the UK and Dutch coastal waters). During certain periods and certain life stages harbour seals and grey seals are more vulnerable to disturbance than other periods:

- The period of birth and nursing for the harbour seal is from May through July.
- The moulting period for the harbour seal is in August.
- Grey seal young are born and nursed in December and January in Dutch coastal area.
- In March and April a large percentage of the grey seals are moulting.

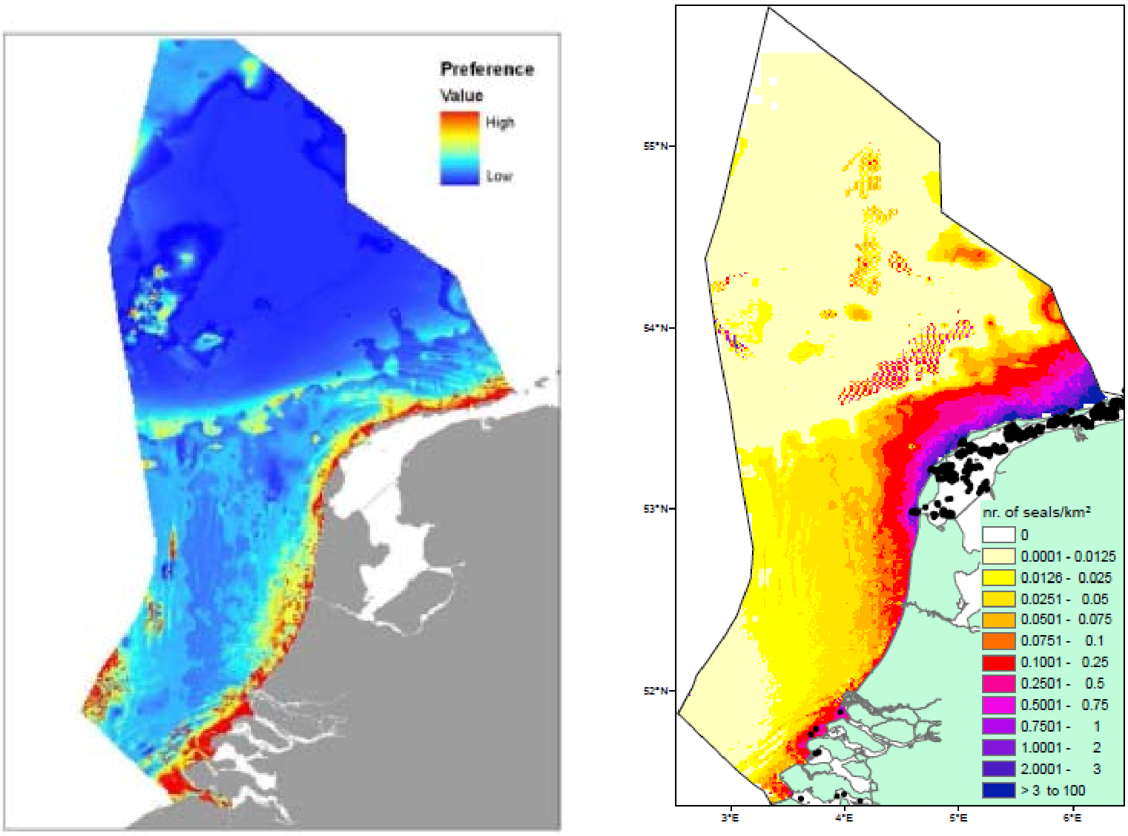


Figure 13 : Predicted distribution map of the harbour seal (right) and grey seal (left) density on Dutch EEZ based on habitat suitability (Brasseur et al., 2012 (right); Brasseur et al., 2009 (left)).

Other marine mammals

Other marine mammals i.e. white beaked dolphin and the Atlantic white sided dolphin, common bottlenose dolphin, common dolphin, minke whale, sperm whale and humpback whale are marine mammals that are either resident in the North Sea or use the North Sea as a migration route (Van der Meij & Camphuysen, 2006, Hammond et al., 2002, Hammond et al., 2013). Observations of these marine mammals in the North Sea are minimal thus patterns in time and space are difficult or impossible to describe. All of the whales and dolphins that occur in the North Sea are included in appendix 4 of the Habitat Directive. In general, there is less information of effects of underwater noise in the North Sea on these marine mammals compared to harbour porpoises and seals. Since information is scarce and the animals are less abundant or even rare in the North Sea, but more importantly assuming that sufficient protection for the most vulnerable species is provided, other less vulnerable species will be sufficiently protected as well. This report therefore only focuses on the effects of underwater noise on the most sensitive species in the North Sea e.g. harbour porpoise.

Fish, fish eggs and fish larvae

Several studies have shown that underwater noise can lead to behavioural changes in fish (Popper & Hastings, 2009; Nedwell et al., 2007, Gausland, 2003 and McCauley *et al.* 2000).

Effects from impulsive sound

Physical and physiological effects on fish from impulsive sound include permanent damage of the swimming bladder, blood vessel and hearing damage. Fish eggs and fish larvae can also be affected by underwater noise with a high sound level (mainly from impulsive sound). The eggs are in a planktonic stage and cannot swim and thus fish eggs cannot escape from high intensity noise. This makes fish larvae and fish eggs vulnerable for impulsive noise (van Damme et al, 2011). The American Fisheries Hydroaccoustic Working Group (FHWG) has described underwater noise threshold value for fish based on several studies. This included a study by Hastings & Popper (2005) on pile driving which observed instant death of fish that were within 12 meters of the monopile and at 1 km distance the fish were shown to have physical damage. Oestman et al. (2009) have suggested several hearing threshold values from impulsive sound for fish of which TTS for larger fish occurs at SEL 187 dB re μPa^2s and for smaller fish (< 2 gram) occurs at 183 dB re μPa^2s. Several fish species such as plaice, sprat, sole and herring are important as staple food for other fishes or young birds. Mainly the fish larvae are predated. The fish eggs and fish larvae are not distributed equally during the year. The concentration of fish larvae in the North Sea is highest in December until May for plaice, January until May for herring and March until June for sole (Bolle *et al.*, 2011). Also the fish eggs and fish larvae of small sand eel and sprat are common in December until May. Therefore, the effects of underwater impulsive noise on fish eggs and fish larvae have more consequences on the population during these months. Fish larvae and fish eggs are adversely affected by underwater noise and this leads to lower recruitment and thus decreases in food availability for other species in the food chain.

However, more recent information shows that fish are less sensitive to underwater noise than Oestman et.al. (2009) suggested. Halvorsen et al. (2012a and b) stated that in some cases adult fish exposed to high intensity noise levels of 216 dB re $1\mu Pa^2s$ do not show any physical damage. Bolle et al (2012) studied the impact of pile driving on common sole larvae and also concluded that a threshold value of 183 dB re 1 μPa^2s for TTS is too conservative. Thus recent knowledge (Bolle et al., 2012 and Halvorsen et al 2012) shows that the impact on initial mortality of fish, fish eggs and fish larvae is less than initially expected. It could be that the precautionary principle for direct mortality on fish eggs and fish larvae was too severe in the case of pile driving. The authors did not study the effects on behaviour and population (e.g. indirect mortality). This is currently under research and until now these effects are not fully understood.

The above mentioned (conservative) thresholds for effects on fish by impulsive sound show that marine mammals are more vulnerable than fish. It is assumed that with mitigation measures for marine mammals also effects on fish are diminished. Therefore, this CBA does only focuses on the effects of impulsive sound on marine mammals. This does not mean that there are no effects or that mitigation measures are not needed for fish, fish eggs and fish larvae.

Effects of ambient sound
When considering ambient noise, effects are different compared to impulsive noise as low frequency noise is the main sound produced. Fish are sensitive for this type of sound as they use low frequencies for communication. A study on freshwater systems (Dol & Ainslie, 2012) show that the noise levels from inland navigation fleet (barges) and recreational boating are within the main hearing frequency range of fish (50 Hz to 2 kHz). Noise levels in rivers are likely to exceed intensity levels of ships compared to those typical at sea. However, effects in fresh and marine water systems are not completely comparable as depth, water chemistry, bathymetry, soil composition, space etc. are important in sound propagation and different in freshwater and marine systems. Communication for fish is important for detecting objects, defending territories, attracting mates and detecting prey and predators (van Opzeeland et al., 2007). Fish themselves produce sound by moving fins, rasping teeth and vibrating the swimming bladder. Based on their sensitivity for sound fish can be divided in two groups, hearing specialist and hearing generalists. Hearing specialists have a connection between the swimming bladder and other air filled cavities and therefore the sound in the inner ear is enhanced. Some specific species can hear ultra sound (sound above 20 kHz). Herring species like *Alosa fallax* and *Alosa alosa*) can hear sound until 180 kHz (van Opzeeland et al., 2007). When background noise is increased, mainly due to shipping (low frequency sound), this can affect the health of fish, their communication (masking), reproduction success, predator-prey relationships and even possibly population levels (Slabbekoorn et al., 2010).

Ainslie & de Jong (2011) ask attention for the effects of underwater noise on fish with a swim bladder. Especially in more shallow water, there is a possibility of high concentrations of fish with a swim bladder. A fish bladder is a gas enclosure that resonates at predictable frequency that depends on the size of the bladder and the static pressure at the fish swimming depth. A sound wave close to the bladder's resonance frequency generates high amplitude pulsations of the bladder. The incoming sound is partly absorbed and partly scattered, resulting in less sound reaching the receiver at the resonance frequency than would otherwise have been the case, and therefore less shipping noise at that frequency. Another consequence is diurnal time dependence, with higher noise expected during daylight hours when the fish are more likely to aggregate in shoals and attenuate the sound less effectively.

Consequences for restrictions of activities

The vulnerable periods of seals, harbour porpoises and fish and the possible effects of underwater noise on these animals, were the reasons to implement the pile driving restriction period from January 1st until July 1st as a condition in the NP Law and FF- Act permit.

APPENDIX B – NOISE MITIGATING MEASURES FOR PILE DRIVING

Selection of the appropriate hammer size (weight and diameter)
Each specific pile diameter requires a specific hammer that matches with this diameter. The delta in costs of hammers may vary from EUR 2,000 to 5,000 per day. Furthermore the availability of a required hammer for a specific site can be an issue. The advantage of a hammer with greater weight and low required pile capacity is that a fewer number of strokes (blows) is needed, thus resulting in a lower noise level than lighter (standard) hammers.

Selection of intensity for hammering: time period of pile driving at a high number of strokes
Developers and contractors indicate the importance of the number of times that underwater noise is produced as a result of pile driving. By pile driving in a short compact period of time developers and contractors argue that the disturbance of marine mammals could be prevented or at least minimised. The use of an ADD deters the marine mammals preventing permanent damage.

Sleeve of steel around the monopile
When designing the plan for the offshore wind farm Gemini. Mitigating measures such as a sleeve were considered. The monopiles have a diameter of 7 meters. Therefore, a large sleeve with a diameter of 7.2 meters would be required around the monopiles which has a weight approximately between 700 to 1000 tons. A sleeve has about the same length as a monopile (40 meters). The sleeve has to be taken along on the installation vessel, which means there is less space available for the installation vessel to transport monopiles. This makes transport more time consuming and less cost effective.
At offshore wind farm Borkum Riffgrund a noise mitigation sleeve was used successfully. The installation sequence had to be optimized to reach the threshold limit. This combination will however not be enough when piles become larger / water depth becomes larger.

Bubble curtain
A bubble curtain is a sheet or “wall” of air bubbles that is produced around the location where the pile driving occurs (Spence et al., 2007). The bubbles are created by forcing compressed air through small holes drilled in metal, PVC rings or hoses. Air bubbles in water create an acoustical impedance mismatch that is effective in blocking noise transmission. Additional attenuation can be achieved by taking advantage of the dispersion and attenuation of underwater noise near the bubbles’ individual resonance frequency due to absorption and scattering (Leighton, 1994; Lee et al., 2012).
Over time, the bubble curtain has evolved to a double bubble curtain and even a triple bubble curtain, which improves the effectivity on reducing noise significantly.
There are many studies of the effectiveness of bubble curtains, including for wind turbine foundations and pile driving activities. Reductions in peak pressure, RMS pressure, and energy have been reported in the literature to range between 5 to 20 dB re 1 $\mu Pa^2 s$ (as summarized by Spence and Dreyer, 2012).
Because the results for individual studies depend so much on the specific application and location, it is difficult to generalize other than to note that bubble curtains can provide a noise reduction that is sufficient enough to avoid fish deaths (Laughlin, 2006;

Reyff, 2009), reduce behavioural disturbance of marine mammals (Lucke et al., 2011; Nehls, 2012), and meet the noise threshold norm (Verfuss, 2012; Wilke et al., 2012).

Bubble curtains are not directly operated from the installation vessel. They require a separate vessel in addition to the installation vessel. Bubble curtains exist in different configurations and work well in shallow locations. When it comes to a deep location currents are disturbing the function of bubble curtains making them not correctly enclosed around a monopile. Furthermore the sound in deeper waters is transmitted at a further distance. Therefore, at deeper locations a more extensive bubble curtain (double or triple) is required.

Hydro hammer (or 'noise mitigation system')
A hydro hammer is an innovative product which consists of a hammer around which a layer is positioned in which air bubbles absorb the noise produced by the hammer. The structure of a hydrohammer is composed and works similarly as a thermos providing an isolative effect on noise. A hydrohammer is able to reduce the noise level at about 12 to 20 dB re 1 μPa^2s.
IHC, one of the main suppliers of hammers, developed hydro hammers which are labelled as a 'noise mitigation system'. This system consists of an air isolated barrier (a sleeve) and a contained bubble screen mitigating high and low frequencies of sound. The figure below illustrates the cross section of a noise mitigation system.

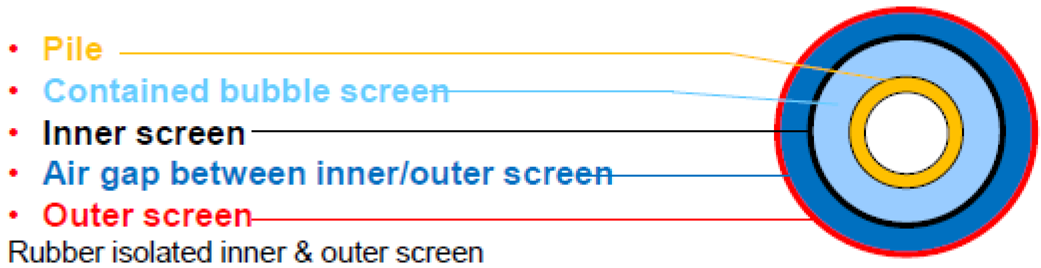


Figure 14 : Cross section of a noise mitigation system (source IHC Hydrohammer, 2014)

This noise mitigation system is applied in different configurations in R&D projects, test projects ('FLOW') and on site in Denmark (farm Riffgat) and Germany (farms Borkum Riffgrund and Butendiek). Different configurations of this system result in different reductions of underwater noise as shown in the figure below.

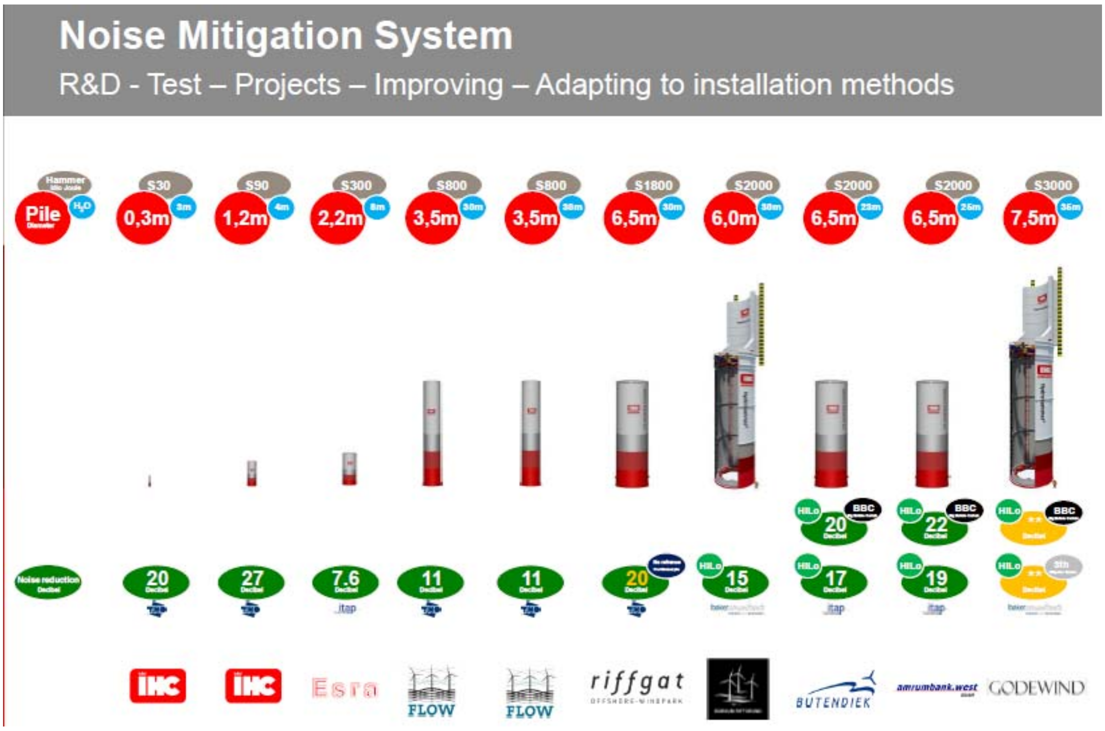


Figure 15 : Development of noise mitigation systems (IHC Hydrohammer, 2014)

Cofferdam

Cofferdams are temporary structures used to isolate an area generally submerged underwater from the water column (CSA Ocean Sciences Inc.., 2014). They are most commonly fabricated from sheet pile driving or inflatable water bladders. Cofferdams typically are dewatered to isolate the pile driving from the water, which attenuates noise by providing an air space between the pile and the water column. If the cofferdam cannot be effectively dewatered, sometimes attenuation can be achieved by using a bubble curtain inside the cofferdam. Dewatered cofferdams generally can be expected to provide attenuation that is at least as great as the attenuation provided by air bubble curtains (ICF Jones & Stokes, 2009).

Stokes et al. (2010) evaluated the potential effectiveness of a massive, dewatered cofferdam for mitigating noise from pile driving of large monopiles during construction of offshore wind farms. Modelling predicted that a massive dewatered cofferdam would reduce noise levels by approximately 20 dB re 1 μPa^{2}s. This is considered to be the upper bound on possible noise mitigation treatment performance.

Setup of dewatered cofferdams is likely to require more time than other similar methods, such as lined barriers and bubble curtains, because the barrier needs to be set on the seafloor such that no leaks are possible.

BSH indicates that in 2014 there were two construction sites where the IHC cofferdam type was applied as single mitigation measure and the hammer energy was reduced to 700 KJ.

For one German offshore wind farm a cofferdam and bubble curtain have been combined. The SEL of this combination was measured and the results showed that a SEL of 155 dB re 1 μPa^{2}s was reached, far below the threshold of 160dB re 1 μPa^{2}s SEL at 750m. Depending on the situation not all mitigation methods are sufficient to reach the threshold level. In this example the location site was relatively shallow, depth of the site was 20-22 meter, and in nature conservation area. The costs of the combination of these mitigation measures were high: EUR 30 million. This was an exception, because it was a special project.

Application of multiple measures

Contractors indicate that a combination of mentioned measures underwater noise can be mitigated to an acceptable sound level. In this way pile driving could be allowed in (part of) the currently restricted period. For offshore wind farms constructed in Germany additional measures to deterrent measures are often also added to a project depending on the size of the project and its location. Extra measures vary from the use of a bubble curtain, reducing the hammer energy or limiting the time of pile driving per pile.

The German authority BSH sets conditions based on the project location, vessel, type of pile, hammer type and the whole project. Once these variables are known, BSH decides which kind of measures might be successful to meet threshold value. BSH tries to apply the best measures per site and adjusts the measures during the project if needed. In the table below the applied noise mitigating measures are shown for eight most recent constructed offshore wind farms in Germany (2008 – 2014).

		Blasenschleier												
Projekt	WEA-Fundament-anzahl und Ø	BBC (HTL)	BBC (Wey)	DBBC (HTL)	DBBC (Wey)	DBBC (Wey HTL)	TBBC (HTL)	TBBC (Wey HTL)	SLBC	DLBC	TLBC	IHC (NMS)	HSD	Wassertiefe
Meerwind	80 MPs, Ø 5,5m			x										22-26 m
GT 1	80 Tripods; je 3 Piles Ø=2,48 m	x							x	x	x			38 - 40 m
NSO	49 Jackets (je 4 Piles Ø=2,4 m)	x	x						x	x				22 - 25 m
DanTysk	80 MP Ø = 6 m	x	x		x	x		x	x					21-32 m
Baltic 2	80 WEA (39 MP: Ø = 5,2 - 6,5 m, 41 JKT: Ø = 3 m) OSS (4 Piles: Ø = 5m)			x			x							MP = 23-35 m, JKT = 35- 44 m, OSS = 32 m
Borkum Riffgrund 1	77 MPs; Ø=5,9 m (+ 1 SBJ)											x		23-28 m
Amrumbank West	30 MP, Ø = 6 m Jackup MPI Discovery	ab Mai 21. MP			x								ab 13. MP	19,5-24 m
	19 MP, Ø = 6 m Kranschiff Svanen	x										x		
	31 MP, Ø = 6 m Jackup MPI Discovery (01.10.: 3 installiert)	x											x	
Butendiek	80 MPs; 6-6,5m Ø	x										x		17-22m

Table 33 : Bubble curtain and other noise mitigating measures applied at German offshore wind farm (BSH, workshop October 2014, Hamburg)

((D) (T) BBC = (Double) (Triple) Big Bubble Curtain; HSD = Hydrosound Damper; NMS = Noise Mitigating System; S/D/T LBC= Single / Double / Triple Length Bubble Curtain)

The information on applied mitigating measures in Germany provides some insights and shows that mitigation measures depend on location and period. The following construction characteristics can differ among offshore wind farms:

- Water depths
- Construction materials
- Currents
- Weather conditions
- Foundation types
- Pile sizes and lengths
- Hammer sizes
- Accompanying ships
- Construction tools (Ram templates, Gripper etc.)
- Etc.

Due to wind farm specific characteristics it is stated that no standard set of measures is available because every project is unique. The German authorities also suggest that noise mitigation systems should be evaluated and adjusted if necessary.

APPENDIX C – COSTS FOR PILE DRIVING MEASURES IN BASELINE ALTERNATIVE

Costs of deterrent measures for pile driving

In the permit for the construction of an offshore wind farm provided by the Dutch authority (Rijkswaterstaat) requirements are stated to apply measures that deter marine mammals during the pile driving period. In the working plan for pile driving a contractor describes the applied deterrent measures and time planning for pile driving. This working plan must be approved by the Dutch authority. A contractor is obliged to use the following deterrent measures before the pile driving process:

- Soft start; pile driving with a hammer at lower power (in kJ) during the first 30 minutes which is part of the regular pile driving procedure for each monopile. This start up is especially used to stabilize the heavy weighted hammer on the sea bottom, but is also as a deterrent measure for marine mammals.
- ADD's; at offshore wind farms Gemini en Luchterduinen the 'fauna guard' is applied. This is an innovative ADD that is able to deter specific marine mammals such as harbour porpoise.
  Earlier also the use of an MMO and a PAM was obliged. PAM is a passive acoustic monitoring device which can detect sound signals. When marine mammals are near the PAM, they can be identified by the frequency of noise that they emit. A MMO analyses the data of the PAM. With the use of these innovative ADD's, a PAM and MMO is not a condition in the permit any more.

A soft start is also applied for operational reasons, as part of the regular pile driving procedure. Therefore, applying a soft start as a deterrent measure is not an extra cost for the contractor.

The costs for the ADD equipment that is purchased and applied by contractors for pile driving are estimated to be EUR 11,000. In most cases a spare ADD is purchased by the contractor to be able to fully comply with the requirements in the permit. This results in the total costs for ADD's per wind farm of about EUR 22,000.

The costs to hire a MMO are EUR 1,000 per day. In most cases two MMOs are used. This results in total costs for the use of MMO's of EUR 2,000 per day. To calculate the total costs of hiring an MMO, the planned activities for offshore wind farm Gemini are used as an example. Approximately 150 monopiles are needed to construct GEMINI. Gemini is made up of two wind farms thus each wind farm consist of 75 wind turbines per farm. To construct one wind farm approximately 150 days are required to install all 75 monopiles (one day to place the vessel and one day of piling). The total costs of MMOs to construct one offshore wind farm of 75 monopiles are estimated to be EUR 300,000 (EUR 2,000 per day x 150 days). The PAM device is similar in costs as a MMO, EUR 1,000 per day. The total costs of a PAM for an offshore wind farm are estimated at EUR 150,000 (EUR 1,000 per day x 150 days).

The total costs for the application of all mentioned deterrent measures for an offshore wind farm are estimated to be around EUR 472,000. The costs of measures are summarized in the table below.

	Cost per measure (EUR)
ADD	22,000
MMO (2 x)	300,000 per park
PAM	150,000 per park
Total costs of deterrent measures	472,000 per park

Table 34 : Costs of potential deterrent measures for pile driving; the use of an MMO and/or a PAM is not required in the Netherlands

<u>Costs for deterrent measures for seismic research</u>
The table below lists the costs for the measures that would be made in the baseline alternative under certain assumptions on the duration and size of the seismic survey (see table).

Measures	Cost per measure (EUR)
Soft start	0*
ADD	22,000**
MMO	84,000**
PAM	84,000**
Total costs of required deterrent measures	212,000

Table 35 : Total costs of standard mitigation measures assuming an average seismic survey takes approximately 6 weeks over an area of 1000 km^2
*soft start is usually done during line changes thus does not lead to extra costs
** Assuming two ADD's are one board including a reserve (this was not discussed during the interviews)
**EUR 2,000 p.d.*42 days (average length of seismic survey)

APPENDIX D – OVERVIEW OF MEASURES

Pile driving

Mitigation Type	Mitigation Technique	Variations	Description	Comments	References
alternative piling installation methods	vibratory pile driving		Uses a vibrating technique	Still in research and development; needs to be combined with regular piling; not a certified technque; need a larger crane thus higher costs; good for sandy bottoms but not for clay ground	BOEM
	press-in piles		The press-in method uses hydraulic rams to push piles into the ground and is characterized as a quieter method than conventional pile driving. Press-in piling machines are self-contained units thatuse static forces to install piles. The machine uses other piles that have already been installed as leverage to install new piles.	Potentially decreases underwater noise; no offshore experience	BOEM
	caste-in-place piles		pile casing is drilled into place and then filled with concrete (Spence et al., 2007)	Application for offshore installation is unknown	BOEM
	pile caps/ jackets		consist of disks of material placed atop a piling to minimize the noise generated by the hamm	Always needs to be combined with piling	BOEM and interview report: Balast Nedam
	Drilling			Innovative technique which has not been applied on a large scael; very expensive different pile design and large weight	BOEM and interview report: Balast Nedam
structure and design	multi pile foundation				BOEM
	lager diameter short pile				BOEM
	large diamter helic piles				BOEM
	change in material choice				BOEM
Noise mitigation measures for impact piling	isolation casings (several types)	IHC Noise mitigation system			IHC. DONG
		BEKA shells	Weyres Beka Shell	Is already used	
	Coffer dams	Cofferdam		Airgap between pile and cylinder	DONG
		Pile-in-Pipe Piling			
	Bubble curtains (big and small)/bubble trees	Big bubble curtain		A common used technique in germany; extra vessel is needed	DONG
		Small bubble curtain		A common used technique in germany	
		Double Big Bubble Curtain		A common used technique in germany	
	Hydro sounds dampers (HSD)	AdBm	American system		DONG
		Hydro Sound Damper	TU braunschweig and Dr Elmar; German System		DONG
		W3G Marine	UK system		DONG
	Acoustic improvement of piling process	prolongation of pulse duration			
		Modification of pile hammers			
	Encapsuled bubbles				
	Fire Hose system (FHS)	Company Meck			
	BLUE Piling Technology	Fistuca			Interview:
	Lammelen				
	ADBM		American system like Hydrosounddamper		
	ESRa: evaluation of systems of ramming noise mitigation				
Low-noise foundations	Gravity base foundations				Interview Eneco, BOEM
	Floatting wind turbines				
	Suction bucket foundations				Interview Eneco
Preventive measures	Detering	Acoustic deterrents : Fauna Guard, Ron Kastelein ADDs			
		Soft start			JNCC guidelines, bruinvisbeschermingsplan
	Passive accoustic Monitoring (PAM)				JNCC guidelines, bruinvisbeschermingsplan
	Marine mammal observer (MMO)				JNCC guidelines, bruinvisbeschermingsplan
	Activity only in daylight hours and under good sighting conditions to detect porpoises				
	Seasonal restrictions				
	Spatial restrictions				
	Notification strandings network prior to acoustic impacts				

Seismic research

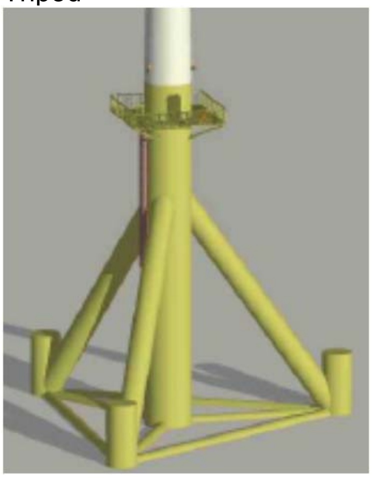
Mitigation Type	Mitigation Technique	Description	Comments	References
Technical and procedural modifications	acoustic deterrents			BOEM
	ramping-up (soft-start)			BOEM
	Conintuous line acquisition	Seismic data is collected by airguns as usual. Instead the ships sails in circles and continuous to shoot when changing lines.	reduces time of survey has been doen by Hansa	Wintershall and Hansa
alternative sources	airguns with a reduced output		May reduce the quality of the data	BOEM
	powerdown			BOEM
	eSource (envioprnmentally friendly seismic source)	the output of high-frequency energy while optimizing it in the seismic band of interest	Not available yet on the market; potentially interesting	Wintershall; Bolt
MVs	Marine Vibroseis		Most mentioned alternative. Still in research and development.	BOEM
	Hydraulic vibroseis			BOEM
	Electronic vibroseis			BOEM
Low Frequency Acoustic Source	LACS 4A		Doesn't exist project is on hold	BOEM
	LACS 8A		Doesn't exist project is on hold	BOEM
	Deep-Towed Accoustics/Geophysics System (DTAGS)		one existant	BOEM
	Low-Impact Seismic Array (LISA)		R&D stage little information	BOEM
	Underwater Tunable Organ-Pipe		early protoptype only used at frequencies above 200 Hz	BOEM
Sound containment (reduce unwanted noise)	Bubble curtains			
	Parabolic reflectors	A Parabolic reflector is towed over the airgun array. The parabolic reflector A15 could consist of an air bubble curtain or could be constructed from solid materials such as neoprene or nitrile foams.	high risk and possibly difficult technique to apply in reality	
	Airgun silencers	The airgun silencer consists of acoustically absorptive foam rubber on metal plates mounted radially	possible high risk; R&D	
Complementary Technologies	Low-Frequency Passive Seismic methods	around the airgun.		
	reinturpritation of old surveys			Wintershall/ Hansa

Shipping

Mitigation Type	Mitigation Technique	Description	Comments	References
Optimizing Propeller design	Twin screw propulsion			IMO
	wing thrusters			IMO
	surface piercing			IMO
	Electric/ Voith-Sneider			IMO
	Contra rotating			IMO
	Propeller pods			IMO
	water jet propulsion			IMO
	Praire system			IMO
	hull/propeller interactions			IMO
Optimizing machinery	Slow and medium speed diesel engines balanced for even load generation between the cylinders and resultant harmonics		Common; use expected to increase	IMO
	Resiliant mountings:	Diameter exhaust/stem pipes resiliently mounted; 2-stage mounts	Rare in commercial large ocean vessels	IMO
	Variable speed pumps/ optimum electric load control		Rare; expected to increase	IMO
	Acoustic filters, desurgers, flow control valvesNot generally used			IMO
	Electric drive propulsion		Common in commercial vessels where reduced vibration is needed (i.e. passenger vessels)l low propulsion efficiancy	IMO/ Marin
	Hybrid power generation		Rarely used; experimental method	IMO
	Airborn noise insulation (cladding of ships interior		Used in cruise vessels; not for machinery rooms in commercial vessels	IMO
	Damping treatment to structure (adding buffering layers under or w/in hull)		Uncommon	IMO
	Active mounting systems		Uncommon	IMO
	Engine synchronization		Not generally used	IMO
Hull design	Optimizing design		Likely to increase in the future due to IMO regulations (vessel/design index); high costs	IMO
	Streamlining underwater appendages; optimizing rudden and skeg designs		possible high costs	IMO
	Reduce turbulence- elliptical bow shape;			IMO
	no abrupt change of shape in the			IMO
	waterline;			IMO
	minimization and alignment of appendages and fittings;		Likely to increase in use	IMO
	flush welds,			IMO
	undistorted plates, and smooth paint works;		Uncommon (non silicon coating common); likely to increase usage	IMO
	optimize hull dimensions			IMO
	Hull cleaning/silicon base coating			IMO
Opperational changes	Reduce ship speed		Reduces sound, fuel costs and CO2 emissions but increases duration of the trip.	Interview Marin
	Rerouting		Minimal effect on reducing marine mammals disturbance; unclear which areas should be avoided for the harbour porpoise	Interview Marin
Noise mitigation systems	Air in propellor			Marin
	Bubble screen within the hull above the proppellor	Method to reduce onboard machinery noise		Marin

APPENDIX E – FOUNDATION TECHNIQUES

Gravity based structure (GBS) 	+ Cost effective in 5 – 40 m water depth + Resistance against ice and vessel impact loads + Concrete is “cheap strength”; less susceptible to material cost escalations - Manufacturing cycle time approx. 3 months, so parallel fabrication necessary - Heavy lift barge needed, unless designed floating - Large prefabrication site needed
Monopile 	+ Fast offshore installation + Cost effective in 5 – 30 m water depth + Proven concept - Critical dynamic response: susceptible to environmental data - Not feasible for large wind turbines - Scour protection needed - Few fabricators with large size rolling equipment - Susceptible to steel price increase

Suction can 	+ Fast offshore installation without heavy equipment, no hammering + Cost effective to 5 – 40 m water depth + Track record in oil and gas industry - Not feasible in case of gravel/boulders - Few experienced companies - Long term stability against dynamic turbine loads unproven
Tripod 	+ Appealing design + Applicable in water depths over 30m + Fast offshore installation - Complicated, fatigue sensitive joint - Expensive fabrication, standardisation is difficult - Joint elevation may limit boat access - relatively high steel weight - Susceptible to steel price increase
Jacket 	+ Fast offshore installation + Cost effective in 30 – 50 m water depth + Less susceptible to sea bed scour + Less sensitive to subsoil conditions (geotechnical) + Relatively small steel quantity, low weight - Labour intensive fabrication: high fabrication costs per ton - Mass production currently not possible - Susceptible to steel price increase

Floating 	+ Only alternative in water depths over 50 m + Option to return to port for major overhaul - Expensive mooring / tension leg system - Unknown behaviour of wind turbines on non-static foundations - Increased cable damage risk

APPENDIX F – LIST OF REGULATIONS PER COUNTRY

Table 36 List of regulations per country updated from original document made by E. Philipp, 2014 (Vattenfall)

Noise mitigation					
Parameters	Country-specific regulations				
	Denmark	Germany	The Netherlands	UK	Belgium
Authority and main legal ground	Danish Energy Agency (DEA)	Federal Maritime and Hydrographic Agency (BSH)	Rijkswaterstaat (Waterwet (Ww), Water act) *Note, it is expected that the law on offshore wind ("Wet windenergie op zee") will become effective the summer of 2015. This means that the minister of Economic Affairs, in agreement with the minister of Infrastructure and the Environment, will become the responsible authority for this law. Rijkswaterstaat remains the responsible authority for the 'waterwet' elements.*	Marine Management Organisation (MMO) - secured through the Marine Licence for each project	Beheerseenheid van het Mathematisch Model van de Noordzee en het Schelde-estuarium (BMM)
Soft start	Yes, but not standardised	Yes	Yes	Yes	Yes, taken up in permit and not standardised
Marine Mammal Observers (MMO) and or/ enforcement of a mitigation zone	No	No	No	Yes, plus live Passive Acoustic Monitoring (PAM) see *Additional information*	No
Acoustic Deterrent Devices (ADD)	Yes, but not standardised	Yes Pinger and Seal scarer	Yes, in general permit	Occasionally, judged on case by case basis see *Additional information*	Yes, taken up in permit

Noise mitigation					
Parameters	Country-specific regulations				
	Denmark	Germany	The Netherlands	UK	Belgium
Seasonal restrictions in pile driving (for marine mammals)	No	No, Pile driving in May-August might be restricted for some projects but no general rule	Yes, no pile driving between 1st January and 1st July, Nb. This is going to be changed. NL is currently reconsidering its policy towards a noise threshold.	No, but some seasonal restrictions for fish spawning ground	Yes, no pile driving between 1st January and 30th April
OWF development in Natura 2000 sites	Yes, conditions apply	Yes 1 OWP but no further consent since establishment of marine spatial planning regulations	Not a *priori* forbidden	Not a *priori* forbidden	Not a *priori* forbidden
Noise thresholds	Yes; SEL_{cum} 183 dB re 1 μPa^2s	Yes, 160 dB re 1 μPa^2s (SEL at 750 m) SEL and 190 dB SPL at 750 m from pile driving event	No	No	Yes; 185 re 1 μPa^2 (zero to peak) at 750 m
Restriction on parallel pile driving	No	No Discussions underway	No more than one construction activity in which piles are driven at any one time	No	No
Noise reduction measures obligatory	No (under discussion)	Yes	No	No (under discussion)	
Additional information / topics		Noise mitigation concept required for 2nd BSH release, 8 month prior construction	Pile driving restrictions not written in Ww - they are included as requirements and conditions *Nb. These conditions*	There are Marine Licences for each project; involved are e.g. the Crown Estate	

Noise mitigation					
Parameters	Country-specific regulations				
	Denmark	Germany	The Netherlands	UK	Belgium
		start	*will change. This will be mentioned in the specific wind site decisions (in Dutch 'kavelbesluiten'). These wind site decisions are part of the law offshore wind.*		
		Daily reporting to the authorities	Restriction period 1st January and 1st July - due to harbour porpoise, fish larvae and seal migration during this period.	Requirement for a Marine Mammal Mitigation Protocol during pile driving - observers/PAMS have been used historically but recent ORJIP study may lead to ADDs being allowed as an alternative, particularly for large arrays where the use of observers is impractical. (pers comment)	
			Since 1st January 2014 coverage of the whole NCPFF act and Nature conservation law has been extended beyond 12 nm		
			The Dutch government is currently investigating how to change the underwater noise regulation. The pile driving restriction		

Noise mitigation					
Parameters	Country-specific regulations				
	Denmark	Germany	The Netherlands	UK	Belgium
			needs to be adapted in order to reach the Dutch offshore wind targets. (pers comment)		

Sources
ORJIP Project 4, Phase 1; Use of Deterrent Devices and Improvements to Standard Mitigation during Piling (A01 - 11/10/13) Luedeke J., 2012, ECUA 2012 11th European Conference on Underwater Acoustics, UW109. Is a German Harbour Porpoise much more sensitive than a British one? Comparative analyses of mandatory measures for the protection of Harbour Porpoises (Phocoena phocoena) during Offshore Wind Farm ramming in Germany, Denmark and the UK Part of Koninklijk Belgisch Instituut voor Natuurwetenschappen http://www.bsh.de/en/Marine_uses/Industry/Wind_farms/index.jsp http://www.rijkswaterstaat.nl/en/, http://www.ens.dk/en/supply/renewable-energy/wind-power/offshore-wind-power Additional references Review of Post-Consent Offshore Wind Farm Monitoring Data Associated with Marine Licence Conditions, Final Report 01/10/2013 http://www.dft.gov.uk/mca/mcga07-home/shipsandcargoes/mcga-shipsregsandguidance/offshore-renewable_energy_installations.htm http://www.gmo.nu/gmoenglish/swedishagencyformarineandwatermanagement.4.778a5d1001f29869a7fff1069.html Uncertainties or missing information Part of Koninklijk Belgisch Instituut voor Natuurwetenschappen

APPENDIX G – LIST OF DOCUMENTS

Ainslie, M.A & C.A.F de Jong (2011). The influence of changing sea conditions on shipping noise, including effects of wind, fish and climate change. Proceedings of the Institute of Acoustics Vol. 33. Pt.5. 2011.

Ainslie, M.A., C.A.F. de Jong, H.S. Dol, G. Blacquière & C. Marasini (2009). Assessment of natural and anthropogenic sound sources and acoustic propagation in the North Sea. TNO-DV 2009 C085. Assignor The Netherlands Ministry of Transport, Public Works and Water Affairs; Directorate-General for Water Affairs.

van der Akker, S. & L. van der Veen, (2013). Sound Solutions; Construction of offshore wind farms without underwater noise. Stichting de Noordzee report.

Arends, E., R. Groen, T. Jager, A. Boon & U. Schadek (2009). Passende Beoordeling Windpark 'BARD Offshore NL 1'.

ASCOBANS, 2010. Final Report of the ASCOBANS Intersessional Working Group on the Assessment of Acoustic Disturbance. Bonn, Germany.

Bellmann, M. A , P. Remmers, H. Holst, S. Gündert, R. Matuschek, T. Drost, M. Müller & M. Schultz von Glahn (2014). Entwicklungen von Schallschutzsystemen von alpha ventus bis Butendiek - Ist ein Stand der Technik erreicht ? -Itap GmbH. Presentation at BSH – Workshop Schallschutz Hamburg, 09.Oktober 2014.

Bolle, L.J, C.A.F. de Jong, S.M. Bierman, P. J.G. van Beek, O.A. van Keeken, P.W. Wessels, C.J.G. van Damme, H.V. Winter, D. de Haan & R.P.A. Dekeling (2012). Common Sole Larvae Survive High Levels of Pile-Driving Sound in Controlled Exposure Experiments. PlosOne (2012) 7(3):1-12.

Bundesministerium für Umwelt, Naturschutz und Reaktrosicherheit (BMU) (2014).Konzept fúr den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee (Schallschutzkonzept).

Camphuysen, C.J. & M. L. Siemensma (2011). Conservation plan for the Harbour Porpoise Phocoena phocoena in The Netherlands: towards a favourable conservation status. NIOZ.

Cato, D.H. (2008). Ocean ambient noise: its measurements and its significance to marine mammals. Proceedings of the Institute of Acoustics. Vol. 30. Pt.5 2008.

Commissie M.E.R., 2012. Toetsingsadvies Commissie m.e.r. 7 juni 2012/ rapportnummer 2633–62 Windpark Q10.

CSA Ocean Sciences Inc., 2014. Quieting Technologies for Reducing Noise During Seismic Surveying and Pile Driving Workshop. Summary Report for the US Dept. of the Interior, Bureau of Ocean Energy Management BOEM 2014-061. Contract Number M12PC00008. 70 pp. + apps.

Dähne, M., A. Gilles, K. Lucke, V. Peschko, S. Adler, K. Krügel & U. Siebert, “Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany”, *Environmental Research Letters*, *8*(2) (2013).

van Damme C.J.G., R. Hoek, D. Beare, L.J. Bolle, C. Bakker, E. van Barneveld, M. Lohman, E. Os-Koomen, P. Nijssen, I. Pennock & S. Tribuhl, 2011. Shortlist Master plan Wind Monitoring fish eggs and larvae in the Southern North Sea: Final report Part A. Wageningen, IMARES. Report number C098/11.

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V., Monitoring Guidance for Underwater Noise in European Seas, Part I: Executive Summary, JRC Scientific and Policy Report EUR 26557 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/29293

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V., Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications, JRC Scientific and Policy Report EUR 26555 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/27158

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V., Monitoring Guidance for Underwater Noise in European Seas, Part III: Background Information and Annexes, JRC Scientific and Policy Report EUR 26556 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/2808

Diederichs, A., H. Pehlke, G. Nehls, M. Bellmann, P. Gerke, J. Oldeland, C. Grunau, S. Witte & A. Rose, 2014. Entwicklung und Erprobung des Großen Blasenschleiers zur Minderung der Hydroschallemissionen bei Offshore-Rammarbeiten. BMU Förderkennzeichen 0325309A/B/C, BioConsult SH, Husum.

Dol, H.S. & M.A. Ainslie, 2012. Noise in Dutch inland waters. TNO report. 20 February 2012.

Dragoset, B., 2000. Introduction to air guns and air-gun arrays. The Leading Edge. p. 892-897.

Energi Styrelsen (2014). Guideline for underwater noise; Installation of impact-driven piles.

EU, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

EU, 2010. Commission decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) (Text with EEA relevance) (2010/477/EU), 2010.

Gausland, I. (2003).Seismic survey impacts on fish hand fisheries. Report for Norwegian oil association. Stavanger.

Geelhoed, S.C.V. , Scheidat, M. , Bemmelen, R.S.A. van (2013). Marine mammal surveys in Dutch waters in 2012. IMARES, 2013 (Report / IMARES C038/13) - 22 p. Den Burg.

Geelhoed, S.C.V. , Scheidat, M. , Bemmelen, R.S.A. van (2014a) Marine mammal surveys in Dutch waters in 2013 IMARES, 2014 (Report / IMARES C027/14) - 22 p. Den Burg.

Geelhoed, S.C.V. , Lagerveld, S. , Verdaat, J.P. , Scheidat, M. (2014b) Marine mammal surveys in Dutch waters in 2014 MARES, 2014 (Report / IMARES C180/14) - 19 p. Den Burg.

Geelhoed S., M. Scheidat, R. van Bemmelen & G. Aarts (2013). Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys in July 2010-March 2011. Lutra 56(1): 45-57.

van der Graaf, A.J., M.A. Ainslie, M. André, K. Brensing, J. Dalen, R.P.A. Dekelin, S. Robinson, M.L. Tasker, F. Thomsen, S. Werner, 2012. European Marine Strategy Framework Directive-Good environmental status (MSFD GES) : report of the technical subgroup on underwater noise and other forms of energy.

Green, 2004, Presentation that addresses the impact of high intensity sonar, airguns & shipping on the marine environment. www.oceanmammalinst.org/underwaternoise.html

Halvorsen, M. B., B. M. Casper, C. M. Woodley, T. J. Carlson and A. N. Popper. (2012a). Threshold for onset of injury in Chinook salmon from exposure to impulsive pile driving sounds. PLoS ONE 7: e38968.

Halvorsen, M.B., B.M. Casper, F. Matthews, T.J. Carlson, A.N. Popper. (2012b). Effects of exposure to pile-driving sounds on the lake sturgeon, Nile tilapia and hogchoker. *Proc. R. Soc. B* rspb20121544.

Hammond P.S., Berggren P., Benke H., Borchers D.L., Collet A., Heide-Jørgensen M.P., Heimlich S., Hiby, A.R., Leopold M.F., Øien N. (2002). Abundance of harbour porpoises and other cetaceans in the North Sea and adjacent waters. J.Appl. Ecol. 39: 361–376.

Hammond, P.S., Macleod K., Berggren P., Borchers D.L., Burt, L., Canadas A., Desportes G., Donovan G.P., Gilles A., Gillespie D., Gordon J., Hiby L., Kuklik I., Leaper R., Lehnert K., Leopold M., Lovell P., Øien N., Paxton C.G.M., Ridoux V., Rogan E., Samarra F., Scheidat M., Sequeira, M., Siebert U., Skov H., Swift R., Tasker M., Teilmann J., van Canneyt O., Vázques J.A. (2013). Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164: 107-122.

Hastings, M.C. & Popper A.N. (2005). *Effects of Sound on Fish*. California Department of Transportation Con-tract 43A0139, Task Order 1. Available from URL: http://www.dot.ca.gov/hq/env/bio/files/Effects_of_Sound_on_Fish23Aug05.pdf.

Heinis, F. (2013). Offshore windpark GEMINI: Effecten van aanleg op zeezoogdieren.

Heinis, F., C.A.F. de Jong & RWS Werkgroep Onderwatergeluid (2015). Cumulatieve effecten van impulsief onderwatergeluid op zeezoogdieren. Maart 2015. Opdrachtgever: RWS DG Zee en Delta.

Hildebrand (2009). Anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395: 5–20.

International Association of Oil and Gas Producers (OGP). 2011. *An overview of marine seismic operations.* OGP Report No. 448. April 2011.

ICF Jones & Stokes. 2009. Final Technical Guidance for Assessment and Mitigation of the Hydro acoustic Effects of Pile Driving on Fish. Prepared for California Department of Transportation, Sacramento, CA. February 2009.

IMO, 2012. International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment. International Maritime Organisation. 6 March 2012.

IMO, 2014. Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life. International Maritime Organisation. MEPC.1/Circ.833. 7 April 2014.

de Jong, C.A.F. & Ainslie, M.A.,2012. “Analysis of the underwater sound during pile driving activities for the Off-shore Wind Park Q7, report TNO 2012 R10081.

de Jong, C.A.F. & B. Binnerts, 2013. Notitie Berekeningen onderwatergeluid voor heiwerkzaamheden Offshore Windpark Gemini (projectnr. 052.04146).

JNCC, 2010. Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from pile driving noise.

Kastelein, R.A., L. Hoek, P. J. Wensveen, J. M. Terhune & C. A. F. de Jong, 2010. The effect of signal duration on the underwater hearing thresholds of two harbour seals (*Phoca vitulina*) for single tonal signals between 0.2 and 40 kHz”. J. Acoust. Soc. Am. **127** (2), February 2010, 1135–1145.

Kastelein, R.A., N. Steen, C.A.F. de Jong, P.J. Wensveen &W.C. Verboom, 2011. Effect of broadband-noise masking on the behavioural response of a harbour porpoise (*Phocoena phocoena*) to 1-s duration 6–7 kHz sonar up-sweeps. J. Acoust. Soc. Am. 129 (4), 2307–2315.

Kastelein, R. (2013). Onderwatergeluid: een van de grootste bedreigingen van zeedieren. *Tijdschrift Geluid*, pp. 9-12.

Kastelein, R.A., L. Hoek, R. Gransier, M. Rambags & N. Claeys, 2014. Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbour porpoise hearing. Journal Acoustic Society America 136 (1): 412-422.

Laughlin, J. 2006. Underwater sound levels associated with pile driving at the Cape Disappointment boat launch facility, wave barrier project. Washington State Department of Transportation, Office of Air Quality and Noise, Seattle, WA. March 2006.

Lee, K.M., M.S. Wochner, and P.S. Wilson. 2012. Mitigation of low-frequency underwater anthropogenic noise using stationary encapsulated gas bubbles. In: Proceedings of the 11th European Conference on Underwater Acoustics, Edinburgh, U.K., 2-6 July 2012.

Leighton, T.G. 1994. The Acoustic Bubble. Academic Press, San Diego, CA.

Lucke, K., U. Siebert, P.A. Lepper & M-A Blanchet, 2009. Temporary shift in masked hearing thresholds in a harbour porpoise (Phocoena phocoena) after exposure to seismic airgun stimuli. J. Acoust. Soc. Am. 125 (6), June 2009, 4060–4070

Lucke, K., P.A. Pepper, M.A. Blanchet, and U. Siebert. 2011. The use of an air bubble curtain to reduce the received sound levels for harbour porpoises (*Phocoena phocoena*). Journal of the Acoustic Society of America 130(5):3406-3412.

Marine Strategy Framework Directive (2008). DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy.

McCauley R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch and K. McCabe (2000). Marine seismic surveys – a study of environmental implications. APPEA JOURNAL 2000: 692-708.

McKenna M.F., D. Ross, S.M. Wiggins & J. A. Hildebrand (2012). Underwater radiated noise from modern commercial ships. J. Acoust. Soc. Am. 131 (1): 92-103.

Miller, P.J.O., Kvadsheim, P., Lam, F.P.A., Wensveen, P.J., Antunes, R., Alves, A.C., Visser, F., Kleivane, L., Tyack, P.L. & L. Doksæter Sivle, 2012. The severity of behavioural changes observed during experimental 189 exposures of killer (*Orcinus orca*), long-finned pilot (*Globicephala melas*), and sperm whales (*Physeter macrocephalus*) to naval sonar. Aquatic Mammals 38: 362-401.

Ministerie van Economische Zaken, 1995. Derde Energienota

Ministerie Infrastructuur en Milieu , 2012. Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel 1 KRM.

Ministerie Infrastructuur en Milieu, 2014a, Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel 2 KRM. Monitoringprogramma.

Ministerie Infrastructuur en Milieu, 2014b. Ontwerp Nationaal Waterplan 2016-2021.

Ministerie Infrastructuur en Milieu, 2014c. Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel 3 KRM. KRM-programma van maatregelen. Bijlage 5 bij het Nationaal Waterplan 2016-2021.

Nedwell J. R., Turnpenny A. W. H. , Lovell J., Parvin S. J., Workman R., Spinks J. A. L., Howell D. (2007). A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. Subacoustech Report 534R1231.

Nedwell, J.R. A G Brooker, S A H Bryant, P J Gardner & J Lovell, 2014. Controlled exposure tests to establish the effects of noise produced by Trailing Suction Hopper Dredgers on common seals. Subacoustech Report No. E234R0208.

Nehls, G., 2012. Impacts of pile driving on harbour porpoises and options for noise mitigation. In: Symposium on protecting the Dutch whale, Amsterdam, 18 October 2012.

Nikolic, P., Klanac, A. & P. Kumar, 2011. Economics and environmental impact of ships speed reduction for the VLCC tanker. as2con-alveus ltd technical report 2011/1.

Oestman, R., Buehler, D., Reyff, J.A. & Rodkin R., 2009. Technical Guidance for Assessment and Mitigation of the Hydro acoustic Effects of Pile Driving on Fish. Prepared for California Department of Transportation.

van Opzeeland, I., H. Slabbekoorn, T. Andringa & C. ten Cate, 2007. Lawaai onder water De invloed van geluid op vissen. Visionair nr. 4 - juni 2007.

OSPAR, 2009. Assessment of the impacts of shipping on the marine environment. Assessment and monitoring series.

Popper, A.N. & M.C. Hastings, 2009. The effects of human-generated sound on fish. Integrative Zoology 2009; 4: 43-52.

Psaraftis, H.N., Kontovas, C. A. & N. M. P. Kakalis, 2009. Speed reduction as an emissions reduction measures for fast ships. *10th International Conference on Fast Sea Transportation FAST 2009, Athens, Greece, October 2009.*

van Puijenbroek, P.J.T.M., F.J. Sijtsma, F.G. Wortelboer, W. Ligtvoet, M. Maarse, (, online first). Towards standardised evaluative measurement of nature impacts: two spatial planning case studies for major Dutch lakes. Environmental Science and Pollution Research (DOI 10.1007/s11356-014-2910-z).

Renilson Marine Consulting Pty Ltd. (Renilson), 2009. Reducing underwater noise pollution from large commercial vessels. Prepared for The International Fund for Animal Welfare. 40 pp.

Reyff, J.A. 2009. Reducing underwater sounds with air bubble curtains. TR News 262:31-3
Richardson, W. J., C. R. Green, C. I. Malme & D. H. Thomson. (1995). Marine Mammals and Noise. Academic Press, San Diego (USA).

Rosenbladt, B., M. Jenkerson & H. Houllevigue. 2013. Marine Vibrator JIP, Sponsored by Shell Exploration and Production Company, ExxonMobil Exploration Company, and Total E&P Research & Technology. BOEM Quieting Technologies for Reducing Noise during Seismic Surveying and Pile Driving Workshop. Silver Spring, MD, 25-27 February 2013.

Sijtsma, F.J, 2006. Project evaluation, sustainability and accountability – Combining Cost-Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA). PhD Thesis, University of Groningen. Stichting REG, nr. 27. Groningen.
http://dissertations.ub.rug.nl/faculties/eco/2006/f.j.sytsma/

Sijtsma, F. J., Heide, C. M. v. d., & Hinsberg, A. v., 2011. Biodiversity and decision-support: integrating CBA and MCA. In A. Hull, E. Alexander, A. Khakee & J. Woltjer (Eds.), Evaluation for participation and sustainability in planning. London: Routledge. (Chapter 9; pp 197-218).

Sijtsma, F. J., Heide, C. M. v. d. & A. van Hinsberg, 2013. Beyond monetary measurement: How to evaluate projects and policies using the ecosystem services framework. Environmental Science and Policy, Volume 32, October 2013, Pages 14–25. http://dx.doi.org/10.1016/j.envsci.2012.06.016.

Slabbekoorn, H., N. Bouton, I. Opzeeland, A. van, Coers, C. ten Cate & A.N. Popper, 2010. A noisy spring: the impact of globally rising underwater sound levels on fish. Trends in Ecology and Evolution 25, 419-427.

Southall, B., L. Nowacek & P. Douglas, 2009. Acoustics in marine ecology: innovation in technology expands the use of sound in ocean science. Marine Ecology Progress Series (395): 1-3.

Southall, B.L., A.E. Bowles, W.T. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene Jr., D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas & Tyack, P. L., 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, 33(4).

Spence, J., R. Fischer, M. Bahtiarian, L. Boroditsky, N. Jones, and R. Dempsey, 2007. Review of Existing and Future Potential Treatments for Reducing Underwater Sound from Oil and Gas Industry Activities. NCE Report 07-001 produced by Noise Control Engineering, Inc. for Joint Industry Programme on E&P Sound and Marine Life.

Stokes, A., K. Cockrell, J. Wilson, D. Davis, & D. Warwick, 2010. Mitigation of Underwater Pile Driving Noise During Offshore Construction: Final Report. Report by Applied Physical Sciences Corp. for the U.S. Department of the Interior, Minerals Management Service, Engineering and Research Branch, Herndon, VA.

The Marine Board, 2008. Position Paper 13. The effects of anthropogenic sound on marine mammals. *A draft research strategy.* June 2008.

Thompson, P.M., K.L. Brookes, I.M. Graham, K. Needham, G. Bradbury & N.D. Merchant, 2013. Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises," Proc.R.Soc. B 280: 20132001 (2013).

TNO (2011). Wintershall – Under water sound air gun arrays. Memo TNO=060-DHW-2011-04820.

Verfuss, T., 2012. Noise mitigation measures & low-noise foundation concepts – state of the art.

Vračar, M.S. & M. Mijić, 2011. Ambient noise in large rivers. J. Acoust. Soc. Am. 130, 1787-1791.

Wales, S.C., & R. M. Heitmeyer, 2002. An ensemble source spectra model for merchant ship-radiated noise, Journal of the Acoustical Society of America 111(3), pp. 1211-1231.

Wilke, F., K. Kloske, & M. Bellman. 2012. ESRa – Evaluation von Systemen zur Rammschallminderung an einem Offshore-Testpfahl. May 2012.

Websites:

https://www.marinetraffic.com
https://www.noordzeeloket.nl
http://www.sonic-project.eu/

APPENDIX H – LIST OF INTERVIEWEES

	Organisation	Interviewee	Relevant Activity	Role in industry
1	Dong Energy	Birte Hansen	Pile driving	Developer
2	Gemini (HVC)	Maarten Bruggeman	Pile driving	Developer
3	Royal HaskoningDHV[9]	Joris Truijens, Erik Zigterman	Pile driving	Engineer, advisor
4	Eneco	Johan Dekker, Systke van den Akker	Pile driving	Developer
5	Vattenfall[9]	Eva Philipp	Pile driving	Developer
6	Carbon Trust[9]	Marco Costa Ros	Pile driving	Special program institute
7	IHC Hydrohammer	Henk van Vessem	Pile driving	Supplier, subcontractor
8	Van Oord	Paul Vernimmen	Pile driving	Contractor
9	Ballast Nedam N.V.[9]	Jurjan Blokland	Pile driving	Contractor
10	Hansa Hydrocarbons	Bert Clever	Seismic survey	Oil & Gas company
11	Wintershall	Yvonne van den Berg	Seismic survey	Oil & Gas company
12	BfN (Bundesamt fur Naturschutz)	Thomas Merck		Research institute
13	Marin	Maarten Flikkema	Shipping	Research institute
14	JNCC	Sonia Mendez	Seismic, shipping, pile driving	Research institute
15	BSH	Nico Nolten	Shipping and pile driving	Research institute
16	Royal HaskoningDHV[9]	Beth Mackey	Seismic, shipping, pile driving	Engineer, advisor
17	University of Groningen[29]	Frans Sijtsma	NA	Expert methodologies cost benefit analyses

[29] * These persons have been consulted, but no interview report is available.