Framework for Assessing Ecological and Cumulative Effects – 2018

Cumulative effects of offshore wind farm construction on harbour porpoises

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Contents

Abstract

The Dutch national Energy Agreement, which was signed in 2013, provided for the development of wind farms in the wind energy areas of Borssele, Hollandse Kust (south) and Hollandse Kust (north) in the period leading up to 2023. With the publication of the 2030 Offshore Wind Energy Roadmap on 27 March 2018, the government presented the planned roll-out for the further realisation of offshore wind energy for the period 2024 through to 2030. This roadmap also included the timetable and the selection of certain designated wind energy areas for the period leading up to 2030.

The North Sea policy document (2016 - 2021) stipulates that site decisions for offshore wind energy must be assessed using the Framework for Assessing Ecological and Cumulative Effects (KEC). In the case of impulsive underwater sound, the main focus here is on the assessment of possible effects on harbour porpoises on the Dutch section of the Continental Shelf. The guiding principle for the assessment of the effects on the harbour porpoise population is that it must be possible to establish, with a high degree of certainty (95%), that the harbour porpoise population will not decline by more than 5% as a result of the construction of offshore wind farms. To ensure that this objective is met, the government sets sound standards for each site that may not be exceeded during the construction of a wind farm. The KEC (update 2016) does not yet take into account the construction of wind farms provided for in the 2030 Offshore Wind Energy Roadmap in the wind energy areas Ten Noorden van de Waddeneilanden, Hollandse Kust (west) and IJmuiden Ver. The effects of the construction of wind farms must be assessed to facilitate the development of wind energy in these areas. A new KEC including these wind energy areas is therefore required (including sound standards).

This report sets out the results of research into the cumulative effects of the construction of offshore wind farms in the period 2016 - 2030, both for the Dutch section of the North Sea and the entire North Sea. That research included first updating, on the basis of the most recent knowledge and insights, the stages in the staged procedure adopted in the 2015 KEC/2016 to determine the effects of the realisation of offshore wind energy on the harbour porpoise population. On the basis of the updated stages, the effects of the realisation of offshore wind energy on the harbour porpoise population for the period 2016 - 2030 were then calculated and sound standards were derived for various ecological standards, that is to say values for the maximum permissible decline in the harbour porpoise population due to the construction of offshore wind farms in the period prior to 2030 that were not included in the Energy Agreement.

It emerges from the results of the calculations that the sound standards for the construction of the wind farms after 2023 may be higher than those for the wind farms in the Energy Agreement. This is partly due to the fact that a new version of the Interim PCoD model was used to calculate the effects on the harbour porpoise population that included the results of an expert elicitation workshop organised in June 2018. Calculations used in this model result in a population reduction that is 3 to 6 times less than the reduction calculated with the earlier version – version 2.1 – of the Interim PCoD model. If a single universal sound standard is assumed of SELss (750 m) = 168 dB re 1 $\mu Pa^2 s$ for the construction of the wind farms after 2023 using wind turbines with a maximum of 10 MW and the sound standards set out in the site decisions for the wind farms planned in the Energy Agreement, it has been calculated for the scenarios described in this report that, for the entire period up to and including 2030, the probability is higher than 95% that the harbour porpoise population on the DCS will decline by no more than 865 animals (= approx. 1.7% of the DCS population). This means that, as a result of the construction of offshore wind farms in the period 2016 - 2030, there is a high degree of certainty that the harbour porpoise population will remain at a level of at least 98% of the current average population.

List of terms and abbreviations

BE	Belgium
DCS	Dutch section of the Continental Shelf
DE	Germany
DK	Denmark
EIA	Environmental impact assessment
EZK (Ministry of)	Economic Affairs and Climate
KEC	Framework for Assessing Ecological and Cumulative Effects
Harbour porpoise disturbance days	the number of impulse days per wind farm multiplied by the number of disturbed harbour porpoises per impulse day
Impulse day	A day on which impulsive sound is produced (at any given time)
iPCoD	Interim PCoD model
LNV (Ministry of)	Agriculture, Nature and Food Quality
PCoD	Population Consequences of Disturbance
Potential biological removal (PBR)	Potential Biological Removal, a term used for setting limits to the additional mortality (caused by human activity) with the aim of the sustainable maintenance of a population
PTS	Permanent Threshold Shift
SCANS	Small Cetaceans in European Atlantic waters and the North Sea
SEL (Sound Exposure Level)	10 times $\log_{10}$ of the ratio of the integral of the square of the sound pressure squared during a defined interval of time (or during a defined event) to the reference value $E_0 = 1\ \mathrm{Pa}^2\mathrm{s}$
SELss	Sound exposure level of a single impulsive sound (SS stands for 'single strike')
SMRU	Sea Mammal Research Unit (University of Saint Andrews)
TNO	Netherlands Organisation for Applied Scientific Research
UK	United Kingdom
Vital rates	In general, the probabilities of survival and reproduction used in the population dynamic models. In the Interim PCoD model, disturbance by impulsive sound affects only the probability of mortality in young, weaned and unweaned animals in their first year of life and the probability of adult females producing offspring.
Vulnerable sub-population	The part of the population that may be disturbed by impulsive sound from a specific project. The size of the vulnerable sub-population is linked to the mobility of the animals: how many different animals could be inside the disturbance area during the course of the project?

1 Introduction

1.1 Background

With the Energy Agreement of 2013, important steps have been and will be taken in the period leading up to 2023 to make Dutch energy supplies more sustainable. The Energy Agreement provides for the development of wind farms in the wind energy areas of Borssele, Hollandse Kust (south) and Hollandse Kust (north). With the publication of the 2030 Offshore Wind Energy Roadmap (Parliamentary Papers 33 561, no. 42) on 27 March 2018, the government presented the planned roll-out of the further realisation of offshore wind energy for the period 2024 through to 2030. This roadmap also included the timetable and the selection of certain designated wind energy areas for the period leading up to 2030.

The North Sea Policy Document (2016 - 2021), which is part of the National Water Plan 2016 - 2021, stipulates that future spatial decisions such as site decisions for offshore wind energy must be assessed on the basis of the Framework for Assessing Ecological and Cumulative Effects (KEC). This assessment framework includes an approach for determining and assessing the cumulative effects of the impulsive underwater sound produced during construction on important populations of marine mammals. Numbers of the harbour porpoise in particular are relatively large at the locations of the planned wind farms, as a result of which the probability of possible effects is also highest for the population of this species. The guiding principle for the assessment of the effects on the harbour porpoise population is that it must be possible to establish, with a high degree of certainty (95%), that the harbour porpoise population (in the Netherlands) will not decline by more than 5% as a result of the construction of offshore wind farms (see Ecological Standard and ASCOBANS Intermezzo). To ensure that this objective is met, the government sets sound standards for each site that may not be exceeded during the construction of a wind farm. The KEC (update 2016) does not yet take into account the construction of wind farms provided for in the 2030 Offshore Wind Energy Roadmap in the wind energy areas Ten Noorden van de Waddeneilanden, Hollandse Kust (west) and IJmuiden Ver. To facilitate the development of wind energy in these areas, these wind farms must also be assessed using the KEC. Since the 2016 update, studies have been published and insights gained that change certain assumptions about the effect relationships. A new KEC (including sound standards) is needed to assess the new wind farms in the 2030 roadmap that also takes new insights into account.

Ecological standard and ASCOBANS Intermezzo

The most relevant question when assessing the consequences of impulsive underwater sound for harbour porpoises is whether it endangers the conservation status of the population. Calculations by Scheidat et al. (2013) show that, according to the PBR method, the threshold of acceptable mortality for the DCS is 272 animals/year for all activities. However, this value refers to direct mortality and does not take into account the possible indirect effect of reduced reproduction. In order to set acceptable limits for the effects of impulsive underwater sound on marine mammals, it is important to bear in mind that the conservation status of harbour porpoises on the DCS has been assessed as moderately unfavourable (Camphuysen & Siemensma 2011). On the basis of the interim recommendations of the EIA Committee on the draft EIA for sites I and II of the Borssele wind energy area, it has therefore been decided that the harbour porpoise population must be maintained at a minimum of 95% of the current population after the construction of offshore wind farms. A further requirement is that there must be a high margin of certainty (95%) that the size of the population will stay above this level despite the construction of the wind farms. On the basis of the data from Geelhoed et al. (2011, 2014), it has been estimated that the population on the DCS consists of 51,000 animals (Scheidat, personal communication). This means that the total population on the DCS may not fall below 48,450 animals as a result of the construction of offshore wind farms in the period 2016 - 2030.

Under the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), the interim target that has been set for harbour porpoises is that the population should not fall below 80% of the carrying capacity level. It is not known what this level is on the DCS. Maintaining the population with a high degree of certainty at a minimum of 95% of its current size after the construction of offshore wind farms for the entire period 2016 - 2030 can be considered a safe choice.

1.2 Objective

The objectives of the new KEC for the underwater sound component are:

- To update the steps described in Heinis et al. (2015) and the staged procedure adopted in the 2015 KEC/2016 for determining the effects of the realisation of offshore wind energy on the harbour porpoise population;

- On the basis of the updated stages, to calculate the effects of the realisation of offshore wind energy on the harbour porpoise population for the period 2016 - 2030;
- To derive sound standards for wind farms constructed in the period leading up to 2030 that were not included in the Energy Agreement.

1.3 Demarcation

Table 1-1 below contains an overview of the Dutch wind farms that have been considered for the 2018 KEC. The three new wind energy areas in the 2030 roadmap have been added to the wind farms included in the calculations for the 2015/2016 KEC and for which site decisions (in some cases in concept form) have now been made (blue).

Table 1-1 Planned wind farms on the DCS for which construction will begin in the period 2016 - 2030.

Wind farm/site	Owner	Size	Operational
Borssele I/II	Orsted	752 MW: 2 x 47 x 8 MW	2020
Borssele III/IV	Blauwwind	731.5 MW: (40 + 37) x 9,5 MW	2020
Hollandse Kust (south) I/II		752 MW: 2 x 47 x 8 MW*	2021
Hollandse Kust (south) III/IV		752 MW: 2 x 47 x 8 MW*	2022
Hollandse Kust (north) V		760 MW: 95 x 8 MW*	2023
Hollandse Kust (west) VI/VII		1,520 MW: 2 x 76 x 10 MW*	2024/2025
Ten Noorden van de Waddeneilanden		760 MW: 76 x 10 MW*	2026
IJmuiden Ver		4,000 MW: 400 x 10 MW*	2027 – 2030

* Scenarios for arrays proposed by RWS used as a basis for the calculations

In addition to the sound from piling for the construction of the wind turbines in the wind farms included in Table 1-1, the 2018 KEC will also take the following sources of impulsive underwater sound into account:

- Sound produced during the geophysical surveys prior to the construction of the wind farms;
- Sound generated during the construction of the transformer platforms;
- Sound generated during the construction of non-Dutch wind farms in the southern North Sea (update of the international scenario in the years leading up to 2030).

The 2018 KEC looks exclusively at the effects on harbour porpoises of impulsive sound produced by the construction of offshore wind farms. The following sources of impulsive underwater sound have therefore <u>not</u> been included:

- Sound produced during seismic exploration for the extraction of oil and gas; this effect has been present for many years and is implicitly taken into account in the Interim PCoD model by the selected population-dynamic parameters;
- Military sonar systems due to the fact that these systems make only a very limited contribution to the total amount of underwater sound in the Dutch part of the North Sea (Ministry of Infrastructure and the Environment 2012; Ainslie et al. 2009);
- The sound from the clearance of ordnance because this is always a short sound burden in which hearing damage is a more important aspect than disturbance (see, for example, Aarts et al. 2016).

In addition, the following are not taken into account:

- the effects (cumulative and otherwise) of wind energy areas already designated in the 2016 - 2021 National Water Plan other than the areas mentioned above. If more site decisions than those included in the 2030 Roadmap are considered in existing or new wind energy areas, the KEC will be updated again;
- Results of the EZK/LNV project Energy Transition and Nature (Buij et al. 2018) as these have not yet been worked up into a policy guideline;
- Possible consequences of an island for the offshore grid in the wind energy area IJmuiden Ver.

1.4 Approach

As explained above, the KEC is intended to assess the future development of offshore wind energy on the basis of a given ecological standard (in this case a maximum 5% reduction in the number of harbour porpoises on the DCS for the entire period up to and including 2030). If this ecological standard is exceeded, restrictions are imposed on the activity (in this case a maximum permissible sound level). To calculate the effect of impulsive sound on the population, different stages (intermediate variables) must be used, each of which is associated with its own uncertainty. The stages and the associated uncertainty levels have been described in Heinis et al. (2015): the 'staged procedure'. The stages will not change in this new KEC but the expectation is that, due to the results of new studies and recent insights relating to effect relationships, there will be less uncertainty in the calculation of the effects *and* in the calculated worst-case population decline. This may create openings for the further development of offshore wind energy. In the completed and ongoing EIA procedures for the wind energy areas of Borssele, Hollandse Kust (south) and Hollandse Kust (north), minor adjustments have already been made to how effects on harbour porpoises are calculated.

On the basis of the new insights relating to the effect relationships, improvements will first be implemented in the KEC procedure. The new procedure will then be applied to the wind farms in the Energy Agreement (Borssele, Hollandse Kust (south) and Hollandse Kust (north)) and the three new wind energy areas Hollandse Kust (west), Ten Noorden van de Waddeneilanden and IJmuiden Ver. The calculations for the new wind energy areas will be made both with and without sound standards. Unlike the wind energy areas in the Energy Agreement, there are not yet any sound standards for the three new wind energy areas. Those standards will be derived in an iterative process starting with sound standards comparable to those in the Energy Agreement (see Annex 1 for the derivation method). This will provide a picture of whether it is possible to realise the planned wind farms within the current system of sound standards and incorporating the latest insights.

1.5 Report structure

Chapter 2 describes the stages in the staged procedure for determining and assessing the cumulative effects of the construction of offshore wind farms in the 2018 version and a comparison with the stages in the 2015 version. In Chapter 3, the modified procedure is applied to the cumulative effects of the construction of offshore wind farms on the harbour porpoise population of the North Sea in the period 2016 - 2030. That chapter presents the calculation results for six scenarios with two thresholds for disturbance, including one international scenario. Chapter 4 contains an assessment of the calculated effects on the harbour porpoise population based on different ecological standards. The results of calculations are then presented in the case of a single uniform sound standard being assumed for the wind farms to be built after 2023. A list of references and eight annexes have been added to the report.

2 The staged procedure to determine the cumulative effects of impulsive underwater sound on the harbour porpoise population - 2018 version

2.1 Overview of stages (unchanged from 2015)

To determine the cumulative effects of impulsive sound on the harbour porpoise population, a staged procedure was developed for the 2015 KEC to quantify the various stages in the effect chain (Heinis et al. 2015). The following stages, as shown in Figure 2-1 in schematic form, can be distinguished:

1. The calculation of a realistic worst case in the propagation of sound due to a single strike for each wind farm; this calculation is based on information about the source sound level, local factors (including bathymetry and bed structure) and knowledge about how sound propagates in water;
2. The calculation of the size of the area disturbed by impulsive sound for each wind farm; this is determined by the calculated sound propagation and a threshold value, possibly frequency-weighted, for the occurrence of a significant behavioural change;
3. The calculation of the number of harbour porpoises disturbed by sound on the basis of the calculated disturbed areas multiplied by the local density of harbour porpoises by season;
4. The calculation of the number of harbour porpoise disturbance days on the basis of the number of disturbed animals per day multiplied by the number of disturbance days;
5. The estimation of the possible impact on the population using the iPCoD model;
6. The assessment of the estimated population reduction and appraisal with reference to the ecological target set by the government (Ministry of Economic Affairs & Ministry of Infrastructure and the Environment, 2016 a, b).

In the sections that follow here, the different stages in the staged procedure are discussed in more detail and a description is given of the improvements that have been made in the 2015 version on the basis of recent insights and research results.

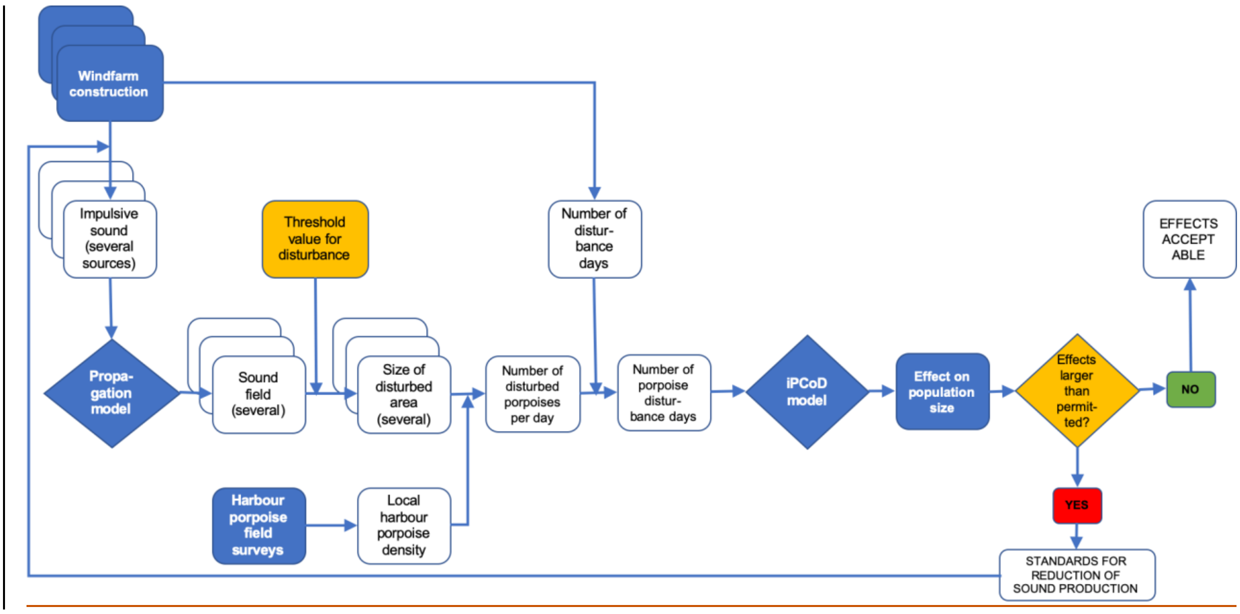


Figure 2-1 Schematic representation of the stages in the staged procedure for determining and assessing the cumulative effects of impulsive underwater sound on harbour porpoises during the construction of wind farms

2.2 Sound propagation

In the 2015 staged procedure, the sound source level was estimated on the basis of piling sound measured during the construction of the Princess Amalia Wind Farm (formerly Q7) assuming the upper limit for various estimates of source level (de Jong & Ainslie, 2012). The source level was scaled to take higher pile-driving energy into account on the basis of the assumption that a fixed percentage of strike energy is converted into sound energy. The spatial distribution of sound (propagation) was calculated using version 1.0 of the TNO Aquarius calculation model on the basis of an energy flux model that takes local factors (bathymetry, sediment properties and wind strength) into account and assumes a point source to calculate propagation.

For the calculation of sound propagation, the KEC was updated using the Aquarius 4 model, which was further developed in the context of the Offshore Wind Energy Programme (WOZEP)[1] (see Annex 1 'Modelling piling sound' & de Jong et al. 2018). The most important changes from the Aquarius 1.0 model used in the past are:

- The semi-empirical point-source spectrum model was replaced in Aquarius 4 by a line-source model that directly includes the properties of the hammer and pile; this means that the effect of the pile diameter, the pile-driving energy and the mass/stiffnesses of the pile + hammer are included directly in the source model.
- Non-linear absorption of sediment below 250 Hz based on the available literature and the Gemini U8 pile measurements (see Binnerts et al. 2016);
- By contrast with the calculations using the Aquarius 1 model, the effect of wind is disregarded in Aquarius 4. The Aquarius 1 calculations did take the effect of wind on sound propagation into account. On the basis of the validation study (Binnerts et al. 2016), it was concluded that the model applied for the disturbance of the water surface by wind results in an overestimation of the propagation loss. In Aquarius 1, however, this was partly offset by the underestimation of the propagation loss resulting from the use of a point-source model for the piles instead of a line source.

The use of the Aquarius 4 model results in more reliable calculation results that are a better match for the sound levels (broadband and otherwise) measured in the field (de Jong et al. 2018). The calculations in the context of the 2018 KEC are based on a realistic worst case for the hammer and pile parameters.

2.3 Disturbance area

The size of the area disturbed by impulsive sound is estimated on the basis of the calculated propagation of the sound of a single piling strike (see § 2.2) and a threshold value for disturbance. The area is determined by the contour around the pile within which the threshold value is exceeded.

In 2015, a threshold value of SEL_{ss} = 140 dB re Pa^{2}s (unweighted, broadband) was assumed. The worst-case assumption here was that the disturbance area would be determined by the contour where the threshold value for disturbance in the lower half of the water column is exceeded (maximum SEL_{ss}). Effects were determined on the basis of the average of the calculated disturbance area with and without the influence of average wind strengths.

An extensive study of the effects of pile-driving on harbour porpoises looking at the first seven wind farms in German waters (Brandt et al. 2018) concluded that '*Declines were found at sound exposure levels exceeding 143 dB re 1 µPa^{2}s (the sound exposure level exceeded during 5% of the piling time, SEL_{05}) and up to 17 km from piling*'. In the calculations for the 2018 KEC, the disturbance areas were determined both on the basis of a threshold value of SEL_{ss} = <u>140</u> dB re 1 µPa^{2}s (unweighted and broadband) and for a value of <u>143</u> dB re 1 µPa^{2}s (unweighted and broadband). As in the 2015 KEC, it is assumed that all harbour porpoises present inside the disturbance contour are equally disturbed. As in the 2015 KEC, the maximum SEL_{ss}in the water column is also assumed (see Annex 1). The effect of wind is not been included (see § 2.2 for the underlying arguments).

Figure 2-3 shows two examples of sound maps with the contours for the areas inside which the limit values of 140 en 143 dB re 1 µPa^{2}s are exceeded. In both cases, the sound is unmitigated sound from piling. The difference in the extent of the disturbed area is attributable to a difference in water depth (17 - 22 m as opposed to 40 - 60 m).

[1]See https://zoek.officielebekendmakingen.nl/kst-33561-26.html (in Dutch) and https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/

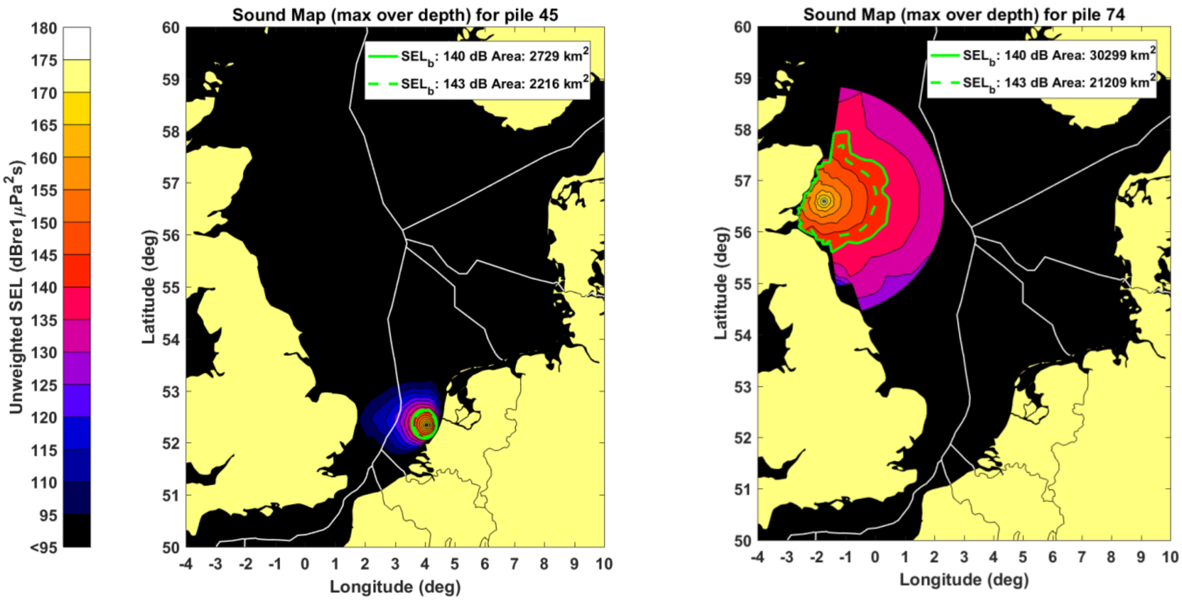


Figure 2-2 Examples of sound maps with contours for the sound levels at which the limit values for disturbance of harbour porpoises are exceeded (in both cases without mitigation). The large difference in the disturbance areas between the two locations is due to differences in water depth.

Comments:

1. It is reasonable to assume that the application of an SEL value weighted with the frequency sensitivity of harbour porpoises' hearing provides a better prediction of the behavioural response but there is as yet no international or national consensus in this respect.
2. Although it should, in principle, be possible to include a more realistic dose-effect relationship than the current '100% disturbance if SEL>threshold', this matter has not been elaborated further in this project.
3. The study by Brandt et al. (2018) assumes a correlation between the observed decline in the presence of harbour porpoises and the measured SELss values. This is expressed as the SELss that is exceeded in a maximum of 5% of the measurements and it therefore represents an upper limit for the sound levels that occur. The Aquarius calculations also adopt a realistic worst-case approach and the calculated SELss can therefore also be seen as an upper limit. A probability percentage cannot be directly linked to the calculation result because the uncertainty of the model calculations for a specific scenario depends in an unknown way on the parameters for the hammer, pile and the locality. Without any proof being available, it seems reasonable to assume that the calculated upper limit is comparable with the upper limit in the observations stated in Brandt et al. (2018). This means that harbour porpoises may be disturbed only when exposure exceeds a threshold value of SELss = 143 dB re 1 µPa^{2}s (unweighted and broadband). The threshold value applied in 2015 KEC, SELss = 140 dB re 1 µPa^{2}s (unweighted and broadband) would therefore seem to be on the cautious side. The present study determined the population effect of disturbance for both thresholds. However, in order to follow as closely as possible the assumptions of the 2015 KEC, it was decided to adopt the worst-case assumption of the lower threshold value of SELss = 140 dB re 1 µPa^{2}s as the basis for setting sound standards for wind energy areas being developed after those in the Energy Agreement.

2.4 Number of disturbed harbour porpoises

The number of potentially disturbed animals is calculated by multiplying the disturbance area by the local harbour porpoise density for the season in which the pile-driving takes place.

For the calculations in the 2015 KEC, the local density of harbour porpoises per season for the DCS was derived from Geelhoed et al. (2011 & 2014). The international scenario was based on data from SCANS II (Hammond et al. 2002, 2013), data from SMRU (Harwood et al. 2014a; Verfuss et al. 2014) and data from various EIA studies for the planned farms in the UK.

For the 2018 KEC, the local density of harbour porpoises was determined on the basis of more recent data from Geelhoed et al. (2018), Gilles et al. (2016) and the results of SCANS III (Hammond et al. 2017). Six areas were identified and the seasonal density of harbour porpoises was estimated using the following method for each of those areas:

- For some areas, summer values (July) were first derived from SCANS-III (Hammond et al. 2017, Table 6) and Table 7 in Geelhoed et al. (2018);
- Spring and autumn values were then calculated on the basis of the ratio of summer values to spring and autumn values from Table 4 in Gilles et al. (2016);
- For the Dutch farms Hollandse Kust and IJmuiden Ver + UK farms offshore East Anglia: average for the years 2010-2017, section D in Figure 1 in Geelhoed et al. (2018);
- For Belgian farms, UK farm Thanet and Dutch Borssele farms: section L in Figure 1 in Hammond et al. (2017, SCANS-III);
- For part of the German farms and the Dutch farm Ten Noorden van de Waddeneilanden: average for the years 2010-2017, the Frisian Front section in Figure 1 in Geelhoed et al. (2018);
- For Danish farms and eastern German farms: section M in Figure 1 in Hammond et al. (2017, SCANS-III);
- For UK farms north of Norfolk (Hornsea): section O in Figure 1 in Hammond et al. (2017, SCANS-III);
- For UK farms offshore Scotland: section R in Figure 1 in Hammond et al. (2017, SCANS-III).

The estimated seasonal density of harbour porpoises on the basis of the above method is shown in Table 2-1. The distribution of the wind farms over the areas can be seen in Figure 2-3.

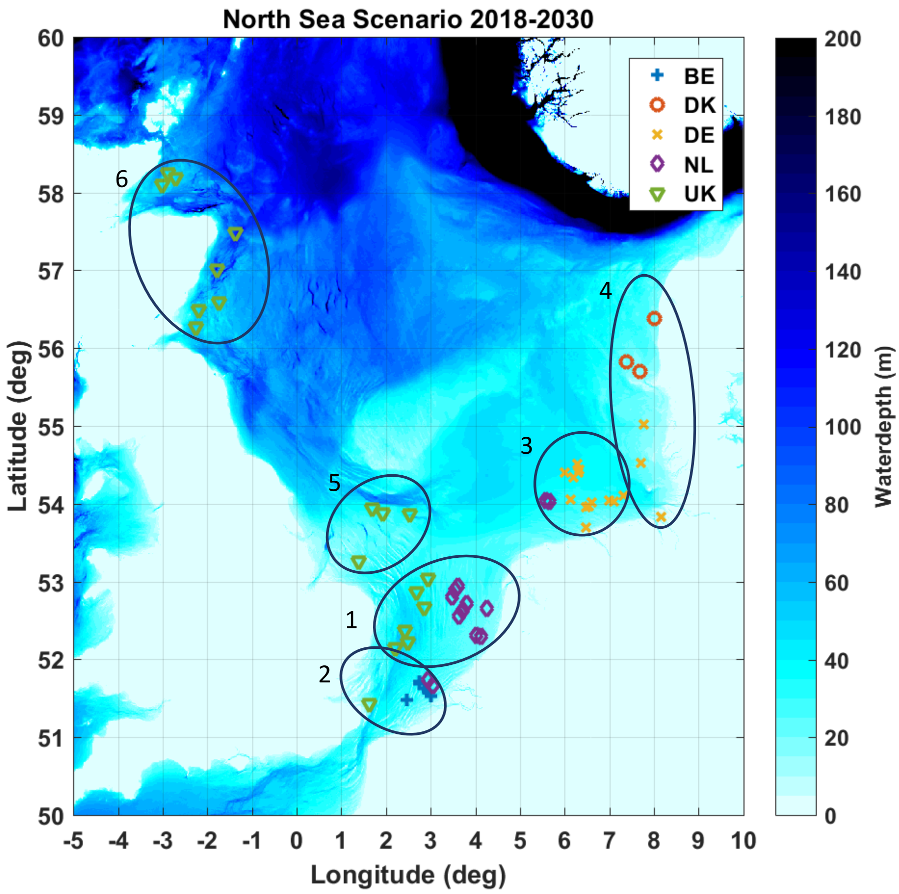


Figure 2-3 Location of the wind farms in areas in the international scenario for determining the local density of harbour porpoises. See Table 2-1 for description of numbers.

Table2-1 Estimated local harbour porpoise population densities by area and season. NL = Netherlands, UK = United Kingdom, BE = Belgium, DE = Germany, DK = Denmark

Area	Individuals/km2		
	Spring	**Summer**	**Autumn**
1 NL Holl. coast + IJmuiden ver, UK East Anglia	0.721	0.698	0.444
2 BE, NL Borssele, UK Thanet	0.628	0.607	0.386
3 DE (part), NL Ten Noorden van de Waddeneilanden	0.812	0.785	0.500
4 DK + DE (part)	0.286	0.277	0.176
5 UK Dudgeon + Hornsea (3x)	0.918	0.888	0.565
6 UK Scotland	0.619	0.599	0.381

2.5 Harbour porpoise disturbance days

The total number of harbour porpoise disturbance days is calculated by multiplying the number of animals that may be disturbed on one day by the number of disturbance days.

For the 2015 KEC, it is assumed that every day/impulse day on which piling takes place (regardless of the duration of the piling) counts as one disturbance day and therefore that the harbour porpoises are disturbed for 24 hours. This approach was determined by pragmatic considerations because the information known at the time about how long disturbance lasts did not provide us with an unequivocal picture (Heinis et al. 2015).

In the 2018 KEC, the calculations were performed with a new version (5) of the Interim PCoD model. This version incorporates the results of another expert elicitation held in June 2018. The harbour porpoise researchers consulted during this expert elicitation agreed that disturbance resulting from the driving of one turbine foundation pile certainly does not last 24 hours and probably does not exceed approx. 6 hours (Booth et al. 2019). This means that if the iPCoD model refers to one disturbance day, it will be interpreted for the assessment of the effects on vital rates as a disturbance of 6 hours and therefore also a 6-hour interruption of foraging (see next § 2.6).

2.6 Effect on population

The possible effects of disturbance by impulsive sound have been stated as an effect on the harbour porpoise population using the Interim PCoD model (SMRU/University of St. Andrews).

Version 2.1 was used for the 2015 KEC (Harwood et al. 2014b). That version used the results of an expert elicitation from 2013. Other assumptions were:

- Total harbour porpoise population in the North Sea: 227,298 (IMMWG, 2013)
- *Vulnerable sub-population* (the proportion of the total population that may be affected): 30,000 for NL, BE and UK South (East Anglia); 99,329 for other UK wind farms, DE and DK.
- Relatively low adult survival of 0.85 (effects of bycatch) and relatively high fecundity of 0.96.

For the 2018 KEC, the effects of disturbance by impulsive sound have been stated as an effect on the harbour porpoise population using version 5 of the Interim PCoD model. This is a complete update of the previous versions based on the expert elicitation of 2013 incorporating the results of the new expert elicitation workshops of February and June 2018. The workshop in June 2018 focused on the experts' opinions relating to the effects of disturbance on the vital rates of harbour porpoises (see Intermezzo for an example from this workshop about the effects of disturbance by impulsive sound on vital rates). In their assessment of the effects of disturbance resulting from piling sound on the vital rates of harbour porpoises, the experts assumed that pile-driving one foundation would result in a disturbance of 6 hours (rather than the 24 hours concluded during the previous elicitation process). This version of the iPCoD model, then, uses the statistics from the experts' opinion about how the number of days during which such disturbance occurs can affect the vital rates of harbour porpoises. The experts were also able to draw on the results of calculations using an energetic model for harbour porpoises developed by the University of St. Andrews in collaboration with the University of Amsterdam to form their opinion about the effect of disturbance on the vital rates. This model drew on the most recent data collected by SEAMARCO in the context of WOZEP and the monitoring programme for the GEMINI wind farm. The model was an important tool for the establishment of a well-founded opinion and, in many cases, it also resulted in more consensus among the experts about the possible effects. During the workshop, it emerged that the effects of disturbance by piling sound on vital rates were thought to be a lot less than those which emerged from the written expert elicitation process in 2013.

Intermezzo - example of expert elicitation judgment (Booth et al. 2019)

The objective of an expert elicitation is to construct a probability distribution to accurately represent the knowledge and beliefs of an expert or group of experts regarding a specific Quantity of Interest (QoI). Here the QoI was the effects of disturbance on the probability of survival and probability of a successful birth (fertility) in different stage classes of harbour porpoise. The Sheffield Elicitation Framework (SHELF) approach was used in the expert elicitation workshop (Oakley and O'Hagan 2016). For each QoI, which has a true value (which is unknown, and which we will call 'X'), each expert was asked to provide their individual judgements regarding a number of parameters, i.e. the plausible limits, median, lower and upper quartiles. The exact structure of each question was agreed with experts in advance of the elicitation and all required definitions were specified and agreed in advance.

The experts were then asked to input their personal judgements into a web-interface form and to send the data to the facilitator (via the form). The judgements were then input into SHELF and distributions were fitted to each individual expert judgement with the best statistical fit (determined in SHELF as the distribution with the lowest sum of squares value). The facilitator then presented the anonymised individual judgements of all experts together to the group (Figure a). During the process, the mechanisms experts had considered in making their individual judgements were discussed among the group.

Following this, the group was asked to reach a 'group consensus' judgement (in the form of a probability distribution). It is important to note here (and stated clearly to experts), that there was no expectation that the experts would reach complete agreement on a probability distribution for a particular QoI. That is because it is unlikely that there is one single distribution that would be accepted as perfectly representing the opinion of all experts. Instead, we asked experts to discuss and agree upon a distribution representing the reasoned opinions of a theoretical external observer, called a Rational Impartial Observer (or RIO). The RIO would not have identical views to any one of the experts but would instead find some merit in all the differing arguments or justifications – and give some weight to each.

The statistical analysis used to estimate the parameters of the relationships required by the interim PCoD model from the results of this 'effects of disturbance' elicitation are described by Donovan et al. (2016).

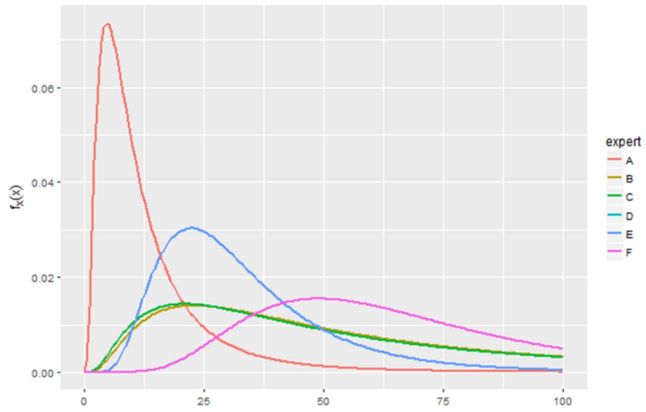


Figure a Theoretical example of individual judgements fitted in SHELF 3.0

The statistical analysis used to estimate the parameters of the relationships required by the interim PCoD model from the results of this 'effects of disturbance' elicitation are described by Donovan et al. (2016).

In the elicitation distributions were generated that provide information on two parameters:

- Firstly, estimates (and associated uncertainty) on the number of days of disturbance that an individual can 'tolerate' before it has any effect in its vital rates. That is, how many days of disturbance would an individual need to experience before a specific vital rate was reduced at all.
- Secondly, estimates (and associated uncertainty) of the number of days of disturbance the same individual would need to experience to reduce the vital rate to zero (i.e. for survival this means death; for fertility, this means no chance of producing a viable offspring).

In order to achieve this, the experts were asked to provide judgements on two separate questions for each harbour porpoise-vital rate combination to capture estimates for the above parameters.

Below, an example of the results of the 2018 workshop on the effects of disturbance on the vital rates of harbour porpoise is given. Following individual judgements, they were presented to the group and experts explored and achieved a group (RIO) consensus as shown below in Figure b.

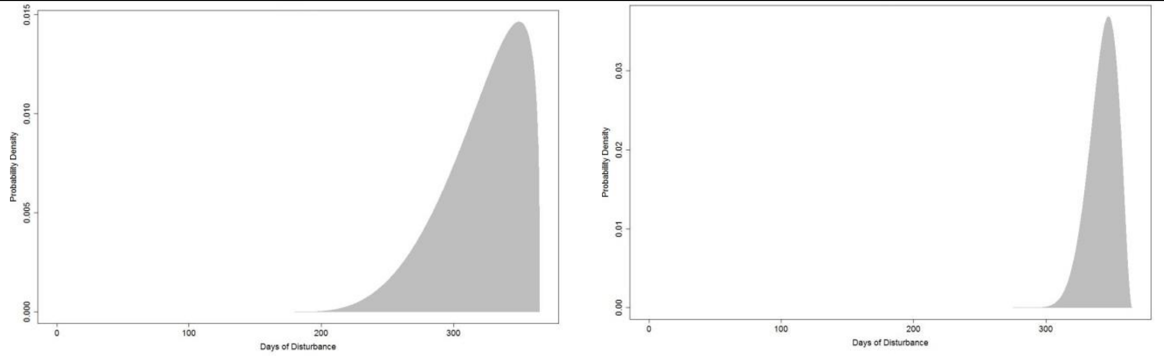


Figure b Probability distributions showing the consensus of the EE for the effect of disturbance on harbour porpoise fertility: the number of days of piling a pregnant female could 'tolerate' before it has any effect on fertility (left panel) and the number of days required to reduce the fertility of the same individual to zero (right panel). N.B. The experts' judgements were based on the assumption that, on average, the behaviour of the animals classified as being disturbed on one day of piling will be altered for 6 hours, and that no feeding will take place during this time.

Experts explored the different possible mechanisms by which harbour porpoise fertility could be impacted by disturbance and agreed that only the energetic considerations are conceivable. As the final third of the year is the most critical (the end of the lactation period for mothers and the beginning of new pregnancies), only in scenarios where animals received repeated exposure throughout the year this would result in significant impacts on fertility. Experts also agreed that it was very unlikely an animal would terminate a pregnancy early as typically the energy reserves of the mother tend to be sufficient (*i.e.*close to the target level) at this time of year.

The calculations with iPCoD version 5 were also based on the following assumptions:

- Total harbour porpoise population in the North Sea: 350,000 (based on Hammond et al. 2002, Hammond et al. 2013, Hammond et al. 2017, Gilles et al. 2016);
- *Vulnerable sub-population*: 350,000 animals (equal to the total North Sea population)[2] because (1) there are no clear indications that there are sub-populations in the harbour porpoise population in the North Sea that are bound to a smaller area, (2) a recent publication shows that the home range of harbour porpoises can be quite large (Nielsen et al. 2018) and (3) the total duration of the scenario to be examined is relatively long at 15 years;
- Relatively low adult survival of 0.85 (effects of bycatch) and relatively high fecundity of 0.96 (the same underlying assumption as in the 2015 KEC);
- As in the 2015 KEC, the iPCoD calculations assume that the development of the harbour porpoise population does not depend on its density. This means that the population will not recover from an effect once it has occurred, such as a decline due to the activities associated with the construction of wind farms. In the latest versions of the iPCoD model (versions 4 and 5), an option has been built in to take into account density-dependent population development. However, it appears that there is not yet enough knowledge to implement this in a meaningful way.

2.7 Effect assessment and appraisal on the basis of the ecological standard

The final stage of the staged procedure is the assessment of the estimated population decline and the assessment on the basis of the maximum permissible effect on the population as determined by the government. The setting of ecological standards, on the basis of which sound standards could be derived using inverse calculation, was not part of the research conducted for the 2015 KEC. In the permit procedure for sites I and II of the Borssele wind energy area, in part on the basis of the recommendations from the Commission on Environmental Assessment, an ecological standard for the wind farms in the Energy Agreement was established with a corresponding system of sound standards. Because the extent of the calculated effects on the population is determined by the local harbour porpoise density (which varies over the course of the year) and the number of foundations to be piled, the sound standards are differentiated by season and number of

[2] John Harwood thinks this is 'quite a strong assumption' (email dated 24 July 2018) and proposes working through a scenario that assumes a site-faithful sub-population. The sensitivity of the modelling results to the size of the vulnerable sub-population for three different sizes was investigated for the Dutch scenario in 2015 (Heinis et al. 2015). These analyses showed that the vulnerable sub-population will play a role starting at population declines that are in the order of magnitude of about half the vulnerable sub-population. The total effect is limited to about 80% of the size of the vulnerable sub-population. See also § 3.3.3 and Heinis et al. (2015).

turbines per site. The principles for that differentiation have been set out in the 2016 KEC update (Ministry of Economic Affairs & Ministry of Infrastructure and the Environment, 2016b).

For the wind farms covered by the Energy Agreement (Borssele I-IV, Hollandse Kust (south) I-IV and Hollandse Kust V (north)), the guiding principle for the assessment of the effects on the harbour porpoise population is that it must be possible to establish, with a high degree of certainty (95%), that the harbour porpoise population on the DCS should not decline by more than 5% as a result of the construction of the ten offshore wind farms in the Energy Agreement (see § 1.1). Assuming an average of 51,000 harbour porpoises on the DCS, this means that the total decline as a result of the roll-out of the Energy Agreement should not exceed 2,550 animals (population decline per wind farm/site should not exceed 255 animals). In order to be able to establish with a high degree of certainty that the population will not decline to a level that is less than 95% of its carrying capacity (which is considered to be the same as the current population size for pragmatic reasons) as a result of human activity, it was decided to use the 5^{th} percentile value of the results of the iPCoD calculations as the limit. This makes it possible to state with a high degree of certainty (a probability of 95%) that the decline in the population will be less than 5%. In reality, this probability is higher because a worst-case approach has always been selected for the assumptions. For the calculation of the population decline, the approximation formula used for the wind farms in the Energy Agreement was the one derived in the context of the 2015 KEC (Heinis et al. 2015). For the results of these calculations, reference is made to the environmental impact assessments underlying the site decisions (and, where appropriate, the draft decisions) for the wind farms in the Energy Agreement (www.bureau-energieprojecten.nl).

In principle, the 2018 KEC is based on the same ecological standard as in 2016. This means that the population decline estimated with a high degree of certainty as a result of the construction of wind farms on the DCS in the period leading up to 2030 may not exceed 5% (and that it must preferably be less). The derivation of possible sound standards for the wind farms after the Energy Agreement (Hollandse Kust (west) VI and VI, Ten Noorden van de Waddeneilanden I and IJmuiden Ver I - IV) has been included in this 2018 KEC.

3 Scenarios and results of calculations

3.1 Approach and underlying assumptions

Six scenarios were developed for the 2018 KEC. They were selected in such a way that the calculations using the staged procedure described in Chapter 2 provide a picture not only of the effects of pile-driving on the construction of the wind farms included in Table 1-1, but also of the effects of:

- Sound produced during the geophysical surveys prior to the construction of the wind farms (for the Dutch wind farms only);
- Sound produced during the construction of the TenneT transformer platforms (for the Dutch wind farms only);
- Sound generated during the construction of non-Dutch wind farms in the southern North Sea (update of the international scenario in the years leading up to 2030).

This led to the following scenarios:

1. NL wind turbine pile-driving without a sound standard for the construction of wind farms after 2023; the sound standards laid down in the site decisions (draft and otherwise) were used for the wind farms in the Energy Agreement;
2. NL wind turbine pile-driving with provisional sound standards for the construction of wind farms after 2023;
3. NL wind turbine pile-driving + pile-driving for platforms with provisional sound standards for the construction of wind farms after 2023;
4. NL wind turbine pile-driving + pile-driving for platforms without sound standards for the construction of wind farms after 2023, including geophysical surveys;
5. NL wind turbine pile-driving + pile-driving for platforms with provisional sound standards for the construction of wind farms after 2023, including geophysical surveys;
6. International scenario for wind turbine pile-driving and, for the Netherlands, pile- driving for the transformer platforms as well (with sound standard DE, NL and BE).

In addition, calculations were made for each of the six scenarios both for a threshold value for disturbance by piling sound for broadband SELss = 140 dB re 1 $\mu Pa^2 s$ and for a threshold value for broadband SELss = 143 dB re 1 $\mu Pa^2 s$ (see § 2.3 for the background to this selection).

With regard to 2, 3, 5 and 6. In the iPCoD calculations with a sound standard, sound standards were used for the Dutch wind farms after 2023 that were derived in a similar way to the sound standards for the wind farms in the Energy Agreement. See Annex 1 for the derivation method and derived standards.

Further details of the scenarios were introduced on the basis of information provided by Rijkswaterstaat Sea and Delta about the construction of wind farms in the North Sea (see Figure 2-3 for locations of wind farms). In addition, the following principles were adopted:

- Only wind farms that are still being constructed were included in the calculations;
- All wind turbines are on monopile foundations;
- Maximum power per turbine (if no specific information is available): 10 MW from 2023 onwards and 12 MW from 2026 onwards;
- Position and area of wind farms built before 2017 were derived from www.4coffshore.com; if there were any uncertainties with respect to the area, a density of 6 MW/km^2 was assumed;
- For wind farms built after 2017, the area is calculated on the basis of a density of 6 MW/km^2;
- Small wind farms less than 10 km offshore that are mostly located in bays are not included due to the shallow water depth, which means that the effects of those farms contribute to only a very limited extent to the total number of harbour porpoise disturbance days;
- For each wind farm, calculations are carried out for one point located in the centre of the wind farm; the depth is based on a realistic worst case (see Annex 2 for the arguments underlying this approach);
- Piling energy is 2000 kJ below a maximum capacity of the wind turbine of 12 MW; for a capacity of 12 MW or more, pile-driving energy of 4000 kJ is assumed. The consequence of these underlying assumptions is that the effects of unmitigated sound are underestimated if the pile-driving energy proves to be higher in practice. If a sound standard is prescribed, it does not matter which hammer is used. However, using a heavier hammer (with a higher pile-driving energy) may make it more difficult to meet the set sound

standard. Unexpectedly large effects of underwater sound due to excessive pile-driving energy can therefore be prevented by setting a standard at all times for the amount of sound produced.
- The pile-driving energy is 2000 kJ for the piles of the transformer platforms.

Geophysical surveys are conducted over a period of one to five years prior to the construction of a wind farm in order to determine the bed structure in different layers and to determine whether any unexploded ordnance is present. These surveys cover both the area where the piling takes place (turbines and platforms) and the routing of the cables to land. In total, there are four surveys:
1. Global survey of the area of the future wind farm;
2. Detailed survey of the locations of the future turbines, platforms and infield cables;
3. Global survey of the cable route;
4. Detailed survey of the cable route.

The sound produced during the geophysical surveys has a different frequency structure than piling sound, with more energy in the higher frequencies. As a result, more realistic (in other words, lower) thresholds of SEL = 75 dB re 1 μPa^2s for sub-bottom profilers and SEL = 130 dB re 1 μPa^2s for sparkers are used as the basis for determining effect distances for disturbance resulting from the use of this equipment. Annex 3 discusses this choice in more detail and explains how disturbance distances and areas were determined on the basis of these threshold values for the various types of geophysical surveys on the DCS for the construction of wind farms.

3.2 Scheduling of scenarios for Interim PCoD model (version 5)

Because of the uncertainties affecting the timetable for the future construction of wind farms in the North Sea, assumptions had to be made when drawing up the construction scenarios. The calendars for the Interim PCoD model were generated on the basis of the following information or underlying assumptions:
- From the Excel file supplied by Rijkswaterstaat: starting date and number of piles;
- No piling in the winter months (December, January, February);
- When only the starting year is known, a random starting date was selected between 1 March and 1 August;
- When the starting date was between 1 January and 1 March, 1 March was selected as the starting date;
- It was assumed in all cases that an average of two piles are driven every three days;
- When an overview had been drawn up of all the construction activities in the North Sea, it emerged that an unrealistically large number of farms were sometimes due to be built at the same time and that the required capacity is probably lacking. It has therefore been assumed that a maximum of six pile-drivers will be available at the same time for the construction of wind farms in the North Sea, two of which will be used in the Netherlands. Construction work was assumed to begin first on farms with the first starting time; the others were postponed until the completion of an ongoing project. As a result of this procedure, the construction of two wind farms, the Belgian Fairy Bank 3 N2000 and the German N-6.6, was postponed until after the end of the period considered in this report and therefore not taken into account; under the original timetable, the construction of these wind farms was due to start in 2030 (see Annex 5);
- The transformer platforms will be installed one year before the construction of the wind turbines; two platform piles will be driven per day;
- Geophysical surveys will be carried out five years (global survey of the wind farm area), two years (global survey of the cable route) and one year (detailed survey of the wind farm area and cable route) before the construction of the transformer platforms in the wind farm (in other words, 6, 3 and 2 years respectively before the piling of the turbine foundations).

An example of a calendar of this kind, in this case for the international scenario, has been included in Figure 3-1. For a more detailed overview of the international scenario, see Annex 4. For the calendar for the Dutch scenario 5 (turbine piles, platforms and geophysical surveys), see Annex 3.

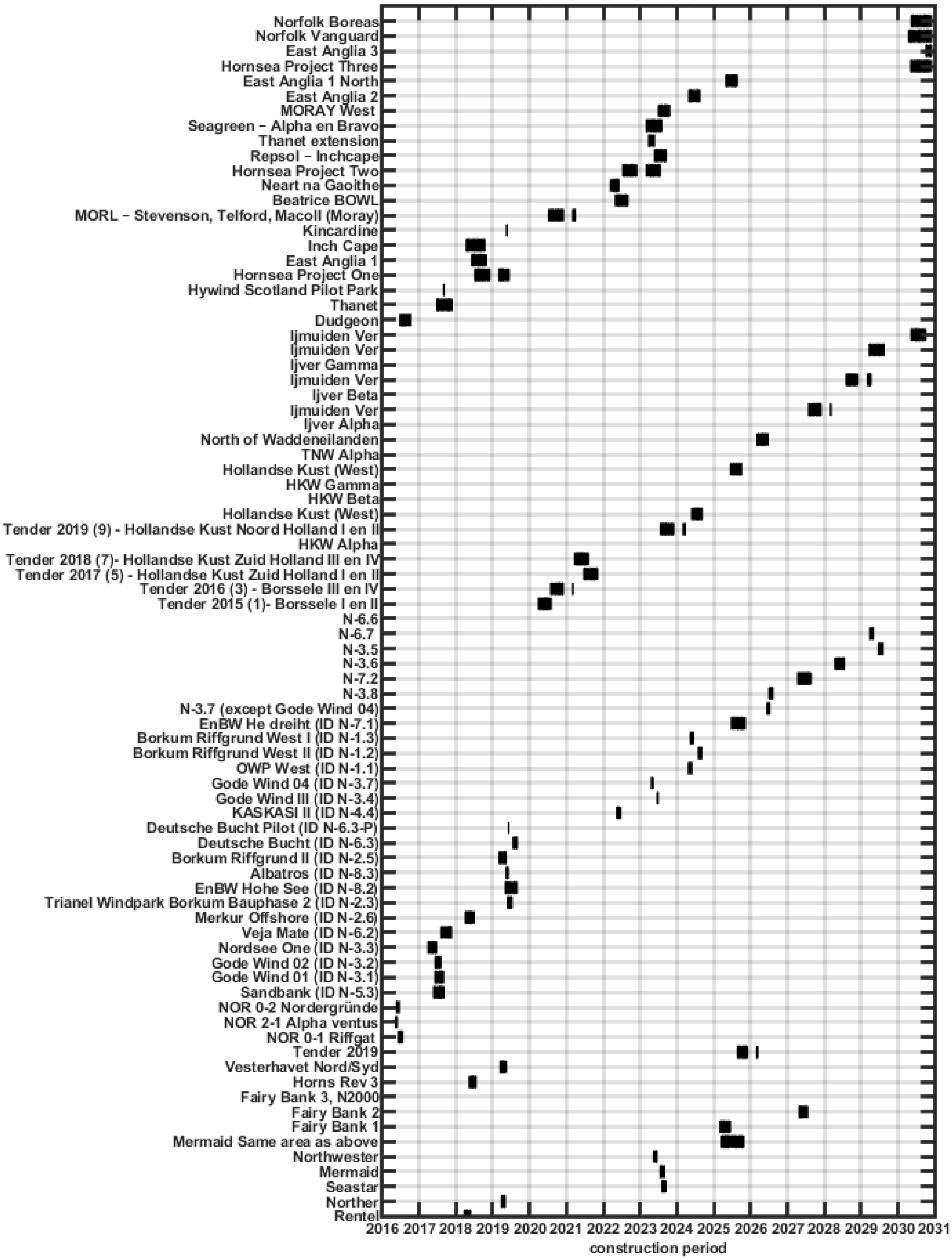


Figure 3-1 Calendar of impulse days for piling turbine foundations in the period 2016 - 2030 in line with scenario 6 (international scenario). The pile-driving for the foundations of the transformer platforms in the Dutch wind energy areas has not been included in this scenario, as can be seen from the empty lines for HKW Alpha, HKW beta, HKW gamma etc.

Table 3-1 provides an overview of the scenarios for the number of days of piling for wind turbine foundations in the North Sea in the period 2016 - 2030 by country and by year. By comparison with the study for the 2015 KEC, in which calculations were made for the period 2016 - 2022, the number of piling days assumed for the same period is lower. This is because the calculations for the 2015 KEC were based on wind turbines with less maximum capacity than is currently taken into account. The total number of piling days in the scenario drawn up at that time was 3,709, with 580 being in Dutch waters. In the scenario drawn up for this study, the total number of piling days in the period 2016 - 2022 was reduced to 2,195 and the number of piling days in Dutch waters to 361. The number of piling days for the years 2016 - 2022 in the 2018 KEC scenario is therefore approximately 60% of the number of piling days in the 2015 KEC scenario.

Table 3-1 Number of days on which there will be pile-driving for the installation of wind turbine foundations in the period 2016 - 2030 in Belgium (BE), Denmark (DK), Germany (DE), the Netherlands (NL) and the United Kingdom (UK) on the basis of the underlying assumptions stated in § 3.1.

	BE	**DK**	**DE**	**NL**	**UK**	**total**	**%total**
2016	0	0	61	0	67	**128**	2%
2017	0	0	291	0	105	**396**	8%
2018	44	50	66	0	407	**567**	11%
2019	29	43	209	0	6	**287**	5%
2020	0	0	0	173	110	**283**	5%
2021	0	0	0	188	0	**188**	4%
2022	0	0	33	0	313	**346**	7%
2023	85	0	24	101	292	**503**	10%
2024	0	0	72	88	80	**240**	5%
2025	220	80	90	82	80	**552**	11%
2026	0	0	48	94	0	**142**	3%
2027	58	0	90	118	0	**266**	5%
2028	0	0	63	118	0	**181**	3%
2029	0	0	48	100	0	**148**	3%
2030	47	0	45	100	810	**1001**	19%
total	**483**	**173**	**1140**	**1162**	**2271**	**5229**	
%total	9%	3%	22%	22%	43%		

3.3 Results of calculations

3.3.1 Disturbed area and harbour porpoise disturbance days

Table 3-2 provides an overview of the total size of the disturbed areas and the number of harbour porpoise disturbance days caused by the piling of the turbine foundations assuming two threshold values for disturbance in the case of the Dutch wind farms where construction will begin in the period 2016 - 2030. It was also assumed here that a standard would be imposed on the broadband sound level that is still present at a distance of 750 m from the piling location. For the wind farms in the Energy Agreement, this standard has already been laid down in site decisions (draft and otherwise). A sound standard was derived in a similar way (see Annex 1) for the wind farms that will be built after 2030. The underlying assumptions described in § 3.1 were also applied. Annex 5 contains a complete overview of the various national and international wind farms in the North Sea covered by this study for which construction will begin in the period 2016 - 2030.

The overview shows that, if a higher threshold value for disturbance of SELss = 143 dB re 1 $\mu Pa^2 s$ is assumed in the calculations for the disturbance area, the disturbed area and therefore the number of harbour porpoise disturbance days is considerably smaller (approximately 37% on average). Furthermore, it emerges that, if one assumes the derived, provisional sound standards for pile-driving for the turbine foundations in the three new wind energy areas, there will be almost three times as many harbour porpoise disturbance days extra by comparison with the wind farms in the Energy Agreement.

Table 3-2 Disturbed area and harbour porpoise disturbance days due to the piling of turbine foundations for the Dutch wind farms that will be built in the period leading up to 2030. The effects of geophysical surveys and piling for transformer platforms have not been included in this overview. See Annex 5 (transformer platforms) and Annex 9 (geophysical surveys).

			Disturbed area (km^2)		Harbour porpoise disturbance days	
Wind farm/site	Number of turbines (= number of piling days)	Sound standard (SELss at 750 m in dB re 1 μPa^2s)	Threshold value for disturbance: 140 dB	Threshold value for disturbance: 143 dB	Threshold value for disturbance: 140 dB	Threshold value for disturbance: 143 dB
Borssele I/II	94	163	285	191	16,538	11,088
Borssele III/IV	79	163	486	289	17,373	10,333
Holl coast (south) I/II	94	165	511	338	27,448	18,142
Holl coast (south) III/IV	94	165	482	323	32,172	21,542
Holl coast (north) V	95	165	559	379	29,422	19,952
Holl coast (west) VI	76	165	718	443	36,836	22,720
Holl coast (west) VII	76	165	734	455	34,820	21,616
North of Wadden	76	167	1741	1029	106,759	63,116
IJmuiden Ver I	100	165	681	429	35,329	22,231
IJmuiden Ver II	100	165	681	429	39,109	24,611
IJmuiden Ver III	100	165	766	466	54,333	33,039
IJmuiden Ver IV	100	165	766	466	48,846	29,693
				Total	478,985	298,083

Table 3-3 contains a summary for the five countries covered by this study of the estimated total number of days during which there will be piling for wind farm construction and the estimated total number of harbour porpoise disturbance days that will result (see Annex 5 for a detailed overview). In the international scenario drawn up for this study, the Netherlands accounts for 21.5% of the number of turbines in the North Sea, but only 2.2 to 2.5% of the number of harbour porpoise disturbance days (depending on the selected disturbance threshold). The largest contribution to the number of harbour porpoise disturbance days in this scenario is made by the United Kingdom: more than 90% (by comparison with 45% of the number of days on which there is pile-driving). The main reason for this is that the calculations assume that no sound standard is imposed in the United Kingdom (http://jncc.defra.gov.uk/page-4274). In addition, because the water is deeper, the disturbed area in a number of locations in the UK is considerably larger than in the shallower southern North Sea, and this also results in an increase in the number of disturbed harbour porpoises (see Figure 2-2).

Table 3-3 Planned number of days on which there is pile-driving for the turbine foundations in the international scenario (6) and the corresponding number of harbour porpoise disturbance days.

	Sound standard (SELss at 750 m in dB re 1 μPa^2s)	**Number of piling days**	**Harbour porpoise disturbance days at threshold value**	
			140 dB	**143 dB**
Belgium	160	437	59,932	34,299
Denmark	-	173	111,113	86,907
Germany	160	1,076	322,245	176,663
Netherlands	163 – 167	1,084	478,985	298,083
United Kingdom	-	2,270	17,820,059	13,256,843
	Total	**5,040**	**18,792,334**	**13,852,795**
	Percentage Netherlands (%)	**21.5**	**2.5**	**2.2**

3.3.2 Effects of scenarios for 2016 - 2030 on the harbour porpoise population

As described in § 2.6 (see Heinis et al. 2015 for a more detailed description), the result of the iPCoD calculation of effects on the population is based on the statistical distributions of the assessment quantified by the experts (reflected in the 'consensus' graph, see § 2.6) of the impact of a temporary disturbance of harbour porpoises on the mortality risk for young, weaned and unweaned animals in their first year of life and on the probability of adult females having offspring, the *vital rates*. Values were derived from these distributions in each iPCoD model run. In order to achieve a representative (and stable) end result, the period for which calculations were performed was extended by ten years to 2040[3] and 10,000 model runs were completed for each scenario. The effect on the population is stated as percentiles[4] of the additional population reduction due to disturbance (= the smaller the percentile value, the greater the probability that this value will not be exceeded). The final, additional, population reduction as a result of the scenarios was calculated as the average with the corresponding variation (standard deviation) for the results of model runs 4,000 - 10,000, in steps of 500 runs. An example of a scenario calculation with iPCoD (5) can be found in Figure 3-2. Similar figures for the other scenarios have been included in Annex 6.

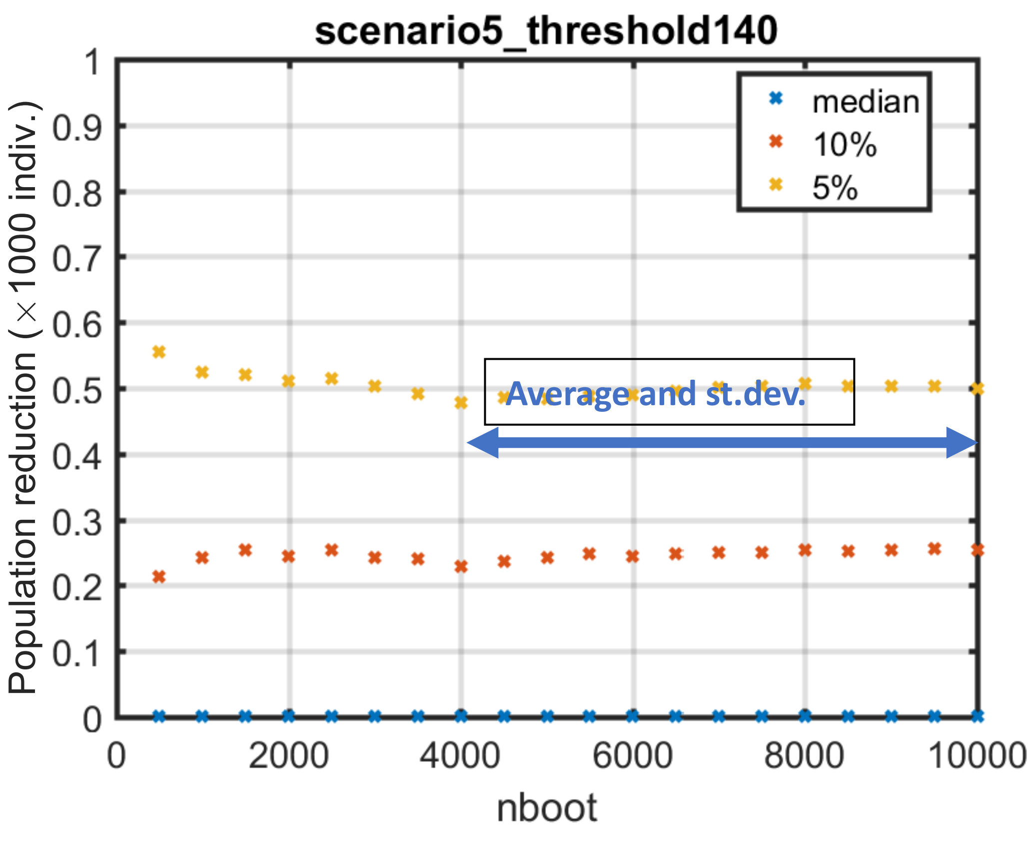


Figure 3-2 Calculated percentiles 5%, 10% and 50% (= median) for the additional population reduction as a result of the activities in the years 2016 to 2030 determined as an average of the calculated differences between the undisturbed and disturbed populations for the years 2031 to 2040 as a function of the number of model runs (nboot).

The results of the iPCoD calculations for all 6 x 2 scenarios are included in Table 3-4 below. The results show that, in the Dutch scenarios, in which the provisional sound standards have been applied, the maximum

[3] The model calculations therefore assume that no wind farms will be built in the period 2030 - 2040.

[4] Meaning of percentile value:

- Median (percentile value 50): the probability is equally high, namely 50%, that the population reduction will be larger or smaller than the displayed value;
- Percentile value 10: there is a 10% probability that the population reduction will be larger than the displayed value (and a 90% chance that the population reduction will be smaller);
- Percentile value 5: there is a 5% probability that the population reduction will be larger than the displayed value (and a 95% chance that the population reduction will be smaller).

permissible decline of 5% of the Dutch harbour porpoise population (= 2,550 animals) will not, with a high degree of certainty (= probability of exceedance ≤ 5%), be exceeded in any scenario.

Table 3-4 Results of Interim PCoD calculations for the scenarios 2016 - 2030. The calculated additional population reduction is stated as the percentiles of 10,000 simulation results averaged for the period 2030 - 2040 (in steps of 500 simulations) and then averaged for the results of simulations 4,000 - 10,000. A percentile value indicates that the probability of exceedance is less than the percentage concerned. Green: high level of certainty (probability of exceedance≤5%) that the decline in the Dutch harbour porpoise population will be less than the maximum permissible number of 2,550 animals determined in 2016.

				Percentiles of average additional population reduction (number of animals)			Standard deviation for percentiles of mean additional population reduction (number of animals)		
scenario	Threshold value (dB)	Piling days	Harbour porpoise disturbance days	50%	10%	5%	50%	10%	5%
1	140	1084	2,991,252	57	2,646	4,104	6	131	32
	143	1084	2,312,886	11	1,541	**2,479**	1	78	92
2	140	1084	478,985	0	231	**438**	0	17	17
	143	1084	298,083	0	150	**300**	0	9	12
3	140	1123	503,519	0	217	**426**	0	8	30
	143	1123	313,296	0	153	**301**	0	4	6
4	140	1574	3086620	68	2,802	4,310	5	80	155
	143	1574	2387902	17	1,595	2,599	3	31	35
5	140	1574	523257	0	238	**451**	0	5	11
	143	1574	333034	0	157	**312**	0	6	15
6	140	4709	18,792,410	5691	24,934	34,001	202	405	495
	143	4709	13,852,852	2937	17,560	23,941	59	417	533

Scenarios:

1. NL wind turbine pile-driving without a sound standard for farms after 2023
2. NL wind turbine pile-driving with a provisional sound standard for farms after 2023
3. NL wind turbine pile-driving + pile-driving for platforms with a provisional sound standard for farms after 2023
4. NL wind turbine pile-driving + pile-driving for platforms without a sound standard for farms after 2023 + surveys
5. NL wind turbine pile-driving + pile-driving for platforms for farms after 2023 + surveys
6. International turbine piles (with sound standard DE, NL and BE)

The estimated number of harbour porpoise disturbance days resulting from the construction of offshore wind farms is, as in the previous calculations with iPCoD (2.1), a good initial measure of the effect on the population calculated with iPCoD (5). However, the relationship is not linear, as can be seen from the logarithmic axes in Figure 3-3. For the relationship derived in 2015, this was the case in the Dutch scenarios for less than 10^6 harbour porpoise disturbance days. As the number of harbour porpoise disturbance days rose, the trend line began to bend due to the limiting effect of the vulnerable sub-population of 30,000 animals selected at the time.

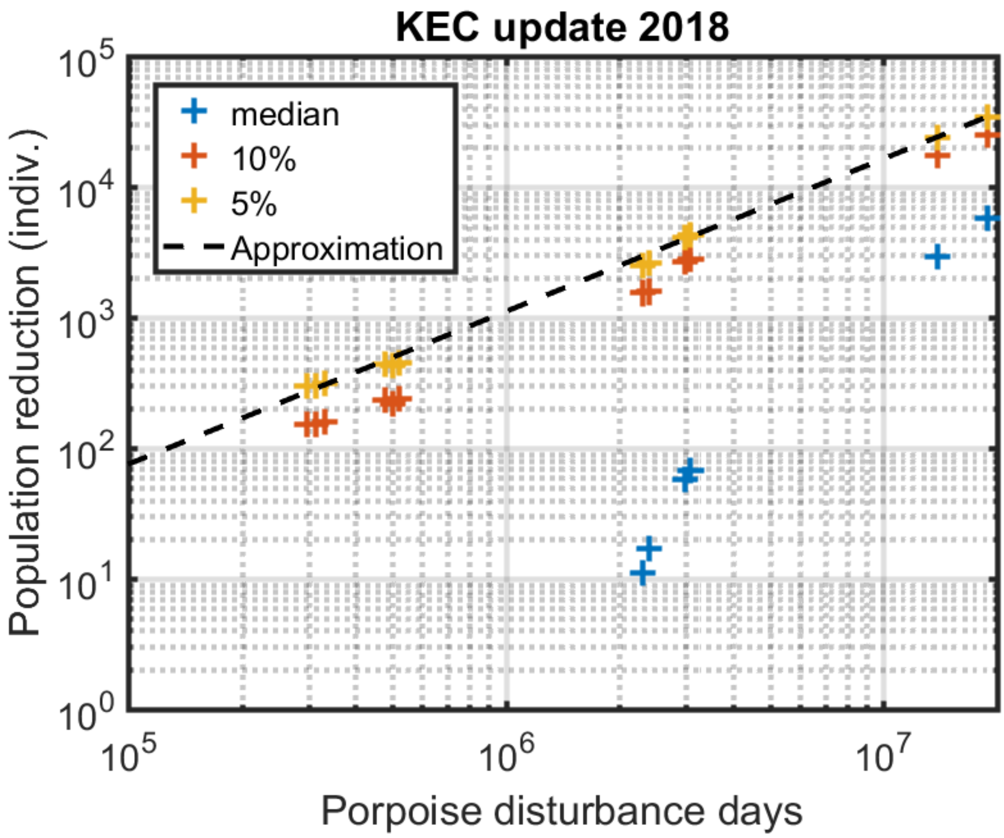


Figure 3-3 Calculated additional population reduction as a function of the number of harbour porpoise disturbance days. The trend line shows the relationship between harbour porpoise disturbance days and the 5% percentile for the additional population reduction.

Assuming the parameters selected in this study for the harbour porpoise population in the North Sea (see § 2.4 and § 2.6), an estimate of a maximum population reduction that will not be exceeded with 95% certainty can be determined without additional iPCoD calculations using the following approximation formula (the dashed line in Figure 3-3):

$$Population\ reduction = 1.06 \times 10^{-4} \times HPDD^{1.17}$$

The population reduction is stated as the number of individuals and HPDD stands for the number of harbour porpoise disturbance days.

N.B. The fact that the relationship is not linear also has implications for estimating the cumulative effects of disturbance caused by the construction of offshore wind farms in EIA studies. It means that the cumulative population reduction due to the construction of several wind farms cannot be calculated by adding up the results calculated for individual farms because the cumulative effects will then be underestimated.

3.3.3 Comparison of results of calculations in 2018 KEC and 2015 KEC

For the 2015 KEC, the effects of the construction of the wind farms in the Energy Agreement on the harbour porpoise population of the DCS were estimated using version 2.1 of the Interim PCoD model. In the case of the 2018 KEC, version 5 was used: a major update of the model for harbour porpoises, common seals and grey seals based on the results of a new expert elicitation (see § 2.6).

A comparison of the results calculated using the two versions of the model can be found in Table 3-5. The results obtained with iPCoD (2.1) have been taken from Table 3-4 in Heinis et al. (2015). iPCoD (5) was used to calculate the population reduction that would result from the construction of wind farms in the period 2016 - 2023 using the same scenarios as those considered for the 2015 KEC. The differences in the calculated number of harbour porpoise disturbance days between the 'old' and the 'new' calculations are attributable to small differences in the model settings[5]. In all cases, these are calculations for the spring.

The results show that the population reduction in the 5% percentile calculated with the new iPCoD model (5) is approximately 3 to 6 times less than the population reduction calculated with version 2.1. In the calculations for the 2015 KEC, variations were also made in the size of the vulnerable sub-population, which was not the case for the 2018 KEC. In the 5% and 10% percentiles, population reduction proved to increase with the size of the vulnerable sub-population. The population reduction is limited to ~80% of the sub-population.

Table 3-5 Comparison of calculated effects on the harbour porpoise population in 2013 (iPCoD 2.1) with those in 2018 (iPCoD 5) for the period 2016 - 2023. The effect on the size of the harbour porpoise population in 2023 is shown as the number of animals given an exceedance probability of 50% (median), 5% and 10%. HPDD = harbour porpoise disturbance days.

		HPDD	**50%**	**5%**	**10%**
NL (vuln. pop. = 350,000)	iPCoD (5)	2,310,566	**-960**	**-4,689**	**-3,572**
NL (vuln. pop. = 66,000)	iPCoD (2.1)	2,326,049	-5,954	-28,363	-20,840
NL (vuln. pop. = 30,000)	iPCoD (2.1)	2,326,049	-7,420	-19,344	-15,872
NL (vuln. pop. = 6,518)	iPCoD (2.1)	2,326,049	-3,748	-5,370	-5,038
International (vuln. pop. = 350,000)	iPCoD (5)	17,095,971	**-9,504**	**-35,299**	**-27,585**
International (vuln. pop. = 227,298)	iPCoD (2.1)	16,439,945	-45,633	-99,794	-88,388

Figure 3-4 shows the relationship between harbour porpoise disturbance days and population reduction for the 2015 KEC scenario (period 2016 - 2023). The yellow, red and blue symbols are the values calculated with iPCoD 5 and shown in Table 3-5 in bold type. The population reduction in the 2015 scenarios (5% percentile value) calculated with iPCoD 2018 proves to be slightly above the trend line derived from the 2018 scenarios. This may be due to the fact that the trend formula, unlike the iPCoD model, does not take into account the distribution of harbour porpoise disturbance days over the years.

[5] In version 5 of iPCoD, the starting date for each calculation year is 1 January, whereas it was 1 June in iPCoD (2.1). The calendar has therefore been adjusted slightly, resulting in a difference in the total number of harbour porpoise disturbance days.

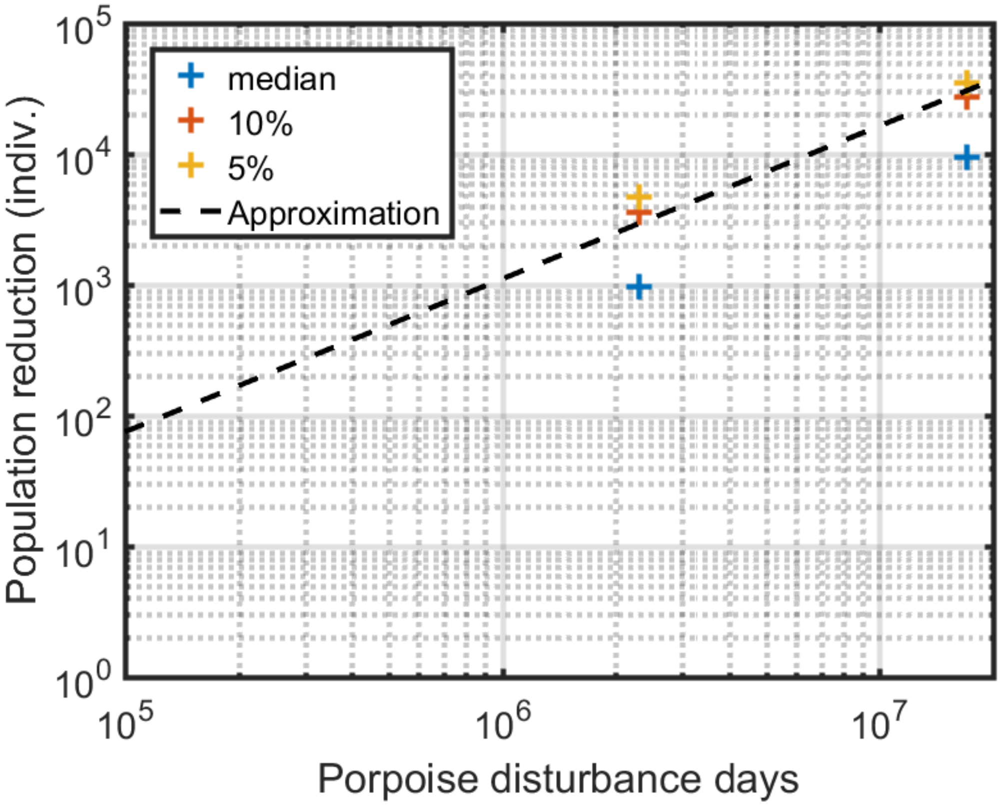


Figure 3-4 Additional population reduction in the Dutch and international scenarios for the KEC 2015 calculated with iPCoD 5; the trend line shown is derived from the 2018 scenarios.

4 Ecological latitude for the construction of wind farms after the construction of the wind farms in the Energy Agreement

4.1 Assessment of results of calculations on the basis of the ecological standard

As in the 2015/2016 KEC, the Dutch government will want to minimise any effects of offshore wind farms on the harbour porpoise population. The requirement of 95% certainty that the population will not decline further as a result of the construction of the wind farms than 95% of the total Dutch harbour porpoise population will therefore be maintained for all offshore wind farms for which studies will be carried out from 2016 onwards and which will be built from 2020 onwards. There are no indications of any change in the total number of harbour porpoises in the Dutch section of the North Sea since the 2015 KEC. It has therefore been assumed, as for the 2015 KEC, that the Dutch harbour porpoise population consists on average of 51,000 animals, which means that the population must remain at a level of at least 48,450 individuals with 95% certainty. This is a maximum reduction of 2,550 individuals.

In this study, calculations were conducted for two scenarios (scenarios 1 and 4, see § 3.1 for a description of the scenarios and Table 3-4 for the results) in which the wind farms in the Energy Agreement are built *with* the application of a sound standard but the wind farms that are built afterwards are not. The results for these scenarios show that, despite the fact that the updated iPCoD (5) model for a similar scenario calculates significantly lower effects (see § 3.3.3), wind farms cannot be built after 2023 without a sound standard being imposed. For example, in scenario 4 (piling foundations + platforms and seismic surveys), there is a 5% probability, depending on the chosen threshold value for disturbance, that the ultimate population reduction will be between 2,599 and 4,310 animals. That ranges from slightly more than, to well above, the acceptable limit of 2,550 animals.

With the provisional sound standards used in the simulations (see § 3.1) for pile-driving for the Dutch wind farms after 2023 (scenario 5), there is a 5% probability of an ultimate population reduction of between 312 and 451 animals (see Table 3-4). That is well below the acceptable limit of 2550 animals.

4.2 Sound standards for offshore wind energy after 2023

4.2.1 Underlying assumptions

To derive sound standards for pile-driving for the NL farms after 2023 (HKW = Hollandse Kust (west), TNvW = Ten Noorden van de Waddeneilanden, IJmVer = IJmuiden Ver), the method used for the wind energy areas in the Energy Agreement has been followed as closely as possible. In addition, the following underlying assumptions were adopted:

- the areas calculated with Aquarius 4.0 in which the disturbance threshold for harbour porpoises of broadband SELss = 140 dB re 1 $\mu Pa^2 s$ is exceeded (worst-case threshold).
- the disturbance contours were calculated for a pile-driving energy of 2,000 kJ[6] and for pile-driving with a SELss sound standard at 750 m of 160 to 190 dB re 1 $\mu Pa^2 s$ in steps of 1 dB.
- the possible reduction in the harbour porpoise population due to the cumulative effects of the construction of all wind farms in the period leading up to 2030 was calculated using the new approximation formula for the relationship between the number of harbour porpoise disturbance days and population reduction (see § 3.3.2).
- the following data were used for the calculation of harbour porpoise densities:
    - Density of harbour porpoises for the wind energy areas Hollandse Kust West and IJmuiden Ver: spring: 0.721; summer: 0.698; autumn: 0.444 individuals/km^2.
    - Harbour porpoise density for the wind energy area Ten Noorden van de Waddeneilanden: spring: 0.812; summer: 0.785; autumn: 0.500 individuals/km^2.

A final possible population reduction of more than 2,550 individuals (with 95% certainty) is not acceptable. In order to ensure there is still latitude for the construction of wind farms after 2030, the government may

[6] Effects of unmitigated sound are underestimated if a higher piling energy than 2,000 kJ is used in practice. If a sound standard is prescribed, it does not matter what pile-driving energy is used; however, using a heavier hammer (with a higher pile-driving energy) may make it more difficult to meet the set sound standard. Unexpectedly large effects of underwater sound due to excessive pile-driving energy can therefore be prevented by setting a standard for the sound produced at all times.

choose to adopt a smaller value for the maximum permissible population reduction. The consequences of other choices in the maximum permissible population reduction for the sound standards to be applied for the construction of wind farms in the period 2016 - 2030 are explained below.

4.2.2 Effect of variation in maximum permissible population reduction on sound standards

Unlike the 2015 KEC, the new approximation formula in § 3.3.2 describes a non-linear relationship between the number of harbour porpoise disturbance days and population reduction. This means that the sound standards for each wind farm cannot be derived directly from a limit for the calculated population reduction for each wind farm. This is possible on the basis of a maximum permissible number of harbour porpoise disturbance days per wind farm. The approximation formula was used to state a number of maximum permissible population reductions in 2030 as a maximum permissible total number of harbour porpoise disturbance days, see Table 4-1.

Table 4-1 Maximum number of harbour porpoise disturbance days (HPDD) derived using the approximation formula for different values for the maximum population reduction

maximum population reduction in 2030 (individuals)	Maximum number of harbour porpoise disturbance days (using inverse approximation formula)*
2,550	2,035,857
1,275	1,125,788
638	622,538
319	344,251

$* \ max.number\ of\ hpdd = (\frac{max.\ population\ reduction}{1.06\ x\ 10^{-4}})^{\frac{1}{1.17}}$

It has been assumed that the sound standards adopted in the site decisions for the construction of the farms in the Energy Agreement will be imposed. For pile-driving in the spring (the worst-case scenario), this results in a maximum number of 146,572 harbour porpoise disturbance days in the period leading up to 2023 (see Table 4-2).

Table 4-2 Calculation of harbour porpoise disturbance days per year for the planned construction of wind farms in line with the SER agreement

id	Name	year	Capacity (MW)	Estimated number of turbines	standard [dB]	Harbour porpoise disturbance days
42	Tender 2015 - Borssele I/II	2020	752	94	163	16,824
43	Tender 2016 - Borssele III/IV	2020	732	79	163	24,160
44	Tender 2017 - Hollandse Kust (south) I/II	2021	752	94	165	34,633
45	Tender 2018 – Hollandse Kust (south) III/IV	2021	752	94	165	32,667
47	Tender 2019 - Hollandse Kust (north) V	2023	760	95	165	38,289
					Total	**146,572**

The maximum permissible number of harbour porpoise disturbance days for the construction of the wind farms in the wind energy areas Hollandse Kust (west), Ten Noorden van de Waddeneilanden and IJmuiden Ver in the years 2024 to 2030 for different ecological standards is obtained by subtracting the number of harbour porpoise disturbance days in Table 4-2 from the maximum number in the second column of Table 4-1. After spreading the maximum number of harbour porpoise disturbance days obtained in this way over the years 2024 - 2030, weighted with the number of MW installed per year, it is possible to calculate the corresponding sound standards for pile-driving shown in Table 4-3 for the stated number of turbine foundations in the spring. Comparable tables with the calculated sound standards for pile-driving for the stated number of turbine foundations in summer and autumn, taking into account the estimate of harbour porpoise density per season, have been included in Annex 7.

Table 4-3 Standards for piling sound (SELss at 750 m in dB re 1 µPa²s) for wind farms after 2023 in accordance with the 2018 KEC given different ecological standards (maximum permissible population reduction in 2030) for pile-driving in the spring (strictest sound standard given the relatively high porpoise density).

id	**Name**	**year**	**Capacity (MW)**	**Estimated number of turbines**	**sound standard [dB] depending on maximum population reduction in 2030 (individuals)**			
					2,550	**1,275**	**638**	**319**
48	Hollandse Kust (west) VI	2024	760	76	183	175	168	162
51	Hollandse Kust (west) VII	2025	760	76	182	175	168	162
53	Ten Noorden van de Waddeneilanden	2026	760	76	173	168	164	160
55	IJmuiden Ver I	2027	1000	100	181	174	168	163
57	IJmuiden Ver II	2028	1000	100	181	174	168	163
59	IJmuiden Ver III	2029	1000	100	181	174	168	162
60	IJmuiden Ver IV	2030	1000	100	181	174	168	162

In the case of unmitigated piling given pile-driving energy of 2,000 kJ, the calculated SELss at a distance of 750 m for the locations on the DCS investigated in this study is approximately 185 dB re 1 µPa²s. Table 4-3 (and the corresponding tables in Annex 7) shows that some form of mitigation will be required in almost all cases to comply with the sound standard and therefore the ecological standard. This also obviates the risk of undesirable major effects if heavier piling hammers are used than those assumed in this study. The lowest sound standard is for the location Ten Noorden van de Waddeneilanden, where the deeper water means that the sound level falls less quickly with distance than in the areas west of the Dutch coast. The calculated sound standards for spring and summer are virtually equal because the harbour porpoise densities do not differ much in those seasons. The standards for the autumn are 2 to 3 dB higher on average because of the lower density.

No account was taken of the possibility of selecting a different value for the number of wind turbines in each farm when deriving the sound standards listed in Table 4-3. This factor was taken into account when setting the standards on the basis of the 2015 KEC. Installing fewer (and therefore larger) turbines in each wind farm means there are fewer days on which harbour porpoises may be disturbed by piling sound. Because the population effect determined using the Interim PCoD model is related to the total number of harbour porpoise disturbance days, the disturbance area per piling day may be larger and the sound standard higher. Table 4-4 shows the calculated sound standards for pile-driving in the spring when installing 15 MW turbines instead of the 10 MW turbines in Table 4-3. Reducing the number of piling days by 30% means that sound standards are generally about 3 dB higher. Comparable tables with the calculated sound standards for pile-driving for the stated number of turbine foundations in summer and autumn, taking into account the estimate of harbour porpoise density per season, have been included in Annex 7.

Table 4-4 Standards for piling sound (SELss in dB re 1 μPa²s at 750 m) for wind farms after 2023 on the basis of the 2018 KEC for different ecological standards (maximum permissible population reduction in 2030), for pile-driving in the spring and for 15 MW wind turbines.

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	1,275	638	319
48	Hollandse Kust (west) VI	2024	760	51	188	180	172	165
51	Hollandse Kust (west) VII	2025	760	51	187	179	172	165
53	Ten Noorden van de Waddeneilanden	2026	760	51	176	171	166	162
55	IJmuiden Ver I	2027	1000	67	186	178	172	165
57	IJmuiden Ver II	2028	1000	67	186	178	172	165
59	IJmuiden Ver III	2029	1000	67	185	178	171	164
60	IJmuiden Ver IV	2030	1000	67	185	178	171	164

4.3 Discussion

4.3.1 Observations and uncertainties

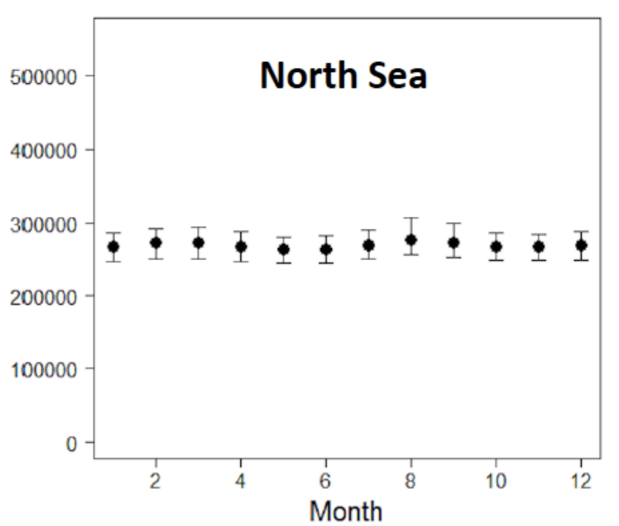
The following observations and/or uncertainties should be pointed out with respect to the results stated in this report.

- It is assumed that pile-driving takes place in the spring: in the autumn, the sound standards stated could, depending on the ecological standard selected, be a few dBs higher because it is assumed that the harbour porpoise density will be lower in the autumn (see § 2.4 and Annex 7); the question is how realistic the assumed differences between the seasons are; on the basis of estimates presented recently by Evans et al. (2018) for the number of harbour porpoises in the North Sea, these differences are hardly present, if at all (Figure 4-1). On a local scale, there are differences between the different seasons but these are not as large as previously assumed.

Table 4. Model-based abundance (N) estimate for harbor porpoises in the North Sea study area (as depicted in Figs. 5–7; area size = 411,000 km²). CV_{all} (N) includes weighted measures of all sources of variance (model specification, mean group size, and detection probabilities).

Parameter	Spring	Summer	Fall
Abundance (N)	372,167	361,146	228,913
CV (model)	0.006	0.001	0.003
CV (group size)	0.01	0.01	0.02
CV (weighted mean esw)	0.18	0.12	0.19
CV (ship g(0))	–	0.16	–
CV_{all} (N)	0.18	0.20	0.19
Lower 95% CI	260,658	243,827	159,264
Upper 95% CI	531,380	534,913	329,022
Density	0.91	0.88	0.56

Note: CI, Confidence interval.



Gilles et al. 2016 | Evans et al. 2018

Figure 4-1 Estimates of the total number of harbour porpoises in the North Sea.

- The calculations are based on a given number of foundation piles and indicative calculations only have been carried out for the situation in which fewer piles are driven to achieve the same maximum installed capacity; if more piles are driven, the number of harbour porpoise disturbance days will increase and so will the possible impact on the harbour porpoise population if the same sound standard is assumed;
- The share of the transformer platforms and the surveys in the total population reduction has not yet been taken into account; this will result in an increase in harbour porpoise disturbance days of about 10%;

- A disturbance threshold of 140 dB re 1 μPa^{2}s has been assumed. At a threshold value of 143 dB re 1 μPa^{2}s, the total number of harbour porpoise disturbance days is 30 - 40% smaller (as is, accordingly, the effect on the population);
- The approximation formula derived on the basis of the results of the calculations applies only to the scenarios studied (the 'calendar');
- By comparison with the results of the calculations with Interim PCoD (5), the maximum uncertainty in the approximation formula is 20%: the points are not exactly on the trend line but slightly below or above it.

4.3.2 Considerations for the adaptation of the ecological standard and consequences for sound standards

The uncertainties set out above in § 4.3.1 can work both ways. Nevertheless, it emerges from the results of the calculations with the revised iPCoD (5) model that, in order to comply with the same ecological standard, the sound standards for the construction of the wind farms after 2023 may be higher than for the wind farms in the Energy Agreement. It also emerges that, even with the least stringent ecological standard, in other words a reduction of the harbour porpoise population by 2,550 animals in 2030, some form of mitigation of the piling sound propagated to the vicinity is required. The following factors determine the selection of a sound standard, whether differentiated or not:

1. Ecological standard: What reduction in the harbour porpoise population as a result of the construction of wind farms in the period 2016 - 2030 is still acceptable?
2. Seasonal variation in harbour porpoise density;
3. Differences in disturbance areas between areas due to differences in water depth;
4. Number of foundations to be piled per wind farm/site.

With regard to 1. It emerged from the calculations that a less stringent sound standard can be used during the construction of the wind farms after 2023. The sound standard to be applied depends on the ecological standard selected. In order to ensure that developments in wind energy remain possible after 2030 and to maintain ecological latitude for other activities that produce sound, the Ministry of LNV and the Ministry of EZK have decided to work on the basis of an ecological standard of a maximum of approximately 1,000 animals.

With regard to 2. In the 2015/2016 KEC, the sound standards to be applied were made dependent on, among other things, the season in which the activities would take place because of assumed seasonal differences in the harbour porpoise density. More recent data about numbers of harbour porpoises in the North Sea indicate that these differences are probably not as large (see § 4.3.1). It was therefore decided not to impose any more seasonal sound standards for the construction of wind farms after 2023.

With regard to 3. The overviews in Table 4-3 and Table 4-4 presented in § 4.2.2 show that, in order to comply with a certain ecological standard, the sound standard to be imposed in the wind farm Ten Noorden van de Waddeneilanden must be stricter than in the wind farms off the Dutch coast because the water is deeper here. For the time being, it has been decided not to differentiate by area and to use a single uniform sound standard for all Dutch areas. This therefore means that a larger effect is permitted locally and that it will be compensated by smaller effects in other, shallower, areas.

With regard to 4. The trend towards wind turbines with larger capacities is still continuing. Whereas the 2015 KEC still assumed 6 MW wind turbines, the calculations for the wind farms after 2023 were carried out for 10 MW wind turbines. To achieve the same maximum installed capacity, fewer wind turbines are therefore needed and the number of days on which there is pile-driving is also lower. In principle, this results in fewer large effects on harbour porpoises at comparable sound levels. This is an additional argument for adopting a less stringent sound standard.

4.4 Consequences of the application of a uniform sound standard of 168 dB after 2023

Given the considerations in the previous section, § 4.3.2, it was decided to investigate the consequences for the harbour porpoise population of applying a single uniform sound standard of 168 dB re 1 μPa^{2}s for the construction of wind farms after 2023 and wind turbines with a maximum capacity of 10 MW. The sound standards in the site decisions were assumed for the construction of the wind farms in the Energy Agreement. The calculations also took into account the harbour porpoise disturbance days resulting from the construction of transformer platforms and the execution of the various geophysical surveys. A summary of the results can be found in Table 4-5. For detailed information about the number of harbour porpoise disturbance days resulting from the construction of transformer platforms and the execution of the geophysical surveys, see Annex 8.

The scenario in Table 4-5 leads to a total number of harbour porpoise disturbance days of **807,969**. It follows from the approximation formula derived in § 3.3.2 that this results in a 5% probability of a reduction in the harbour porpoise population of **865** animals (= approximately 1.7% of the harbour porpoises on the DCS).

Table 4-5 Harbour porpoise disturbance days resulting from the construction of the wind farms in the Energy Agreement based on the application of the sound standard adopted in the site decisions for pile-driving in the spring and the wind farms after 2023 based on the application of a single uniform sound standard of SELss = 168 dB re 1 μPa^2s (750 m) for both the turbine foundations (for 10 MW turbines) and the transformer platforms.

id	Name	year	Capacity (MW)	Estimated number of turbines	standard [dB]	Harbour porpoise disturbance days
42	Tender 2015 - Borssele I/II	2020	752	94	163	16,824
43	Tender 2016 - Borssele III/IV	2020	732	79	163	24,160
44	Tender 2017 - Hollandse Kust (south) I/II	2021	752	94	165	34,633
45	Tender 2018 – Hollandse Kust (south) III/IV	2021	752	94	165	32,667
47	Tender 2019 - Hollandse Kust (north) V	2023	760	95	165	38,289
Total disturbance days resulting from the piling of the turbine foundations for the Energy Agreement						**146,572**
48	Hollandse Kust (west) VI	2024	760	76	168	58,193
51	Hollandse Kust (west) VII	2025	760	76	168	59,892
53	Ten Noorden van de Waddeneilanden I	2026	760	76	168	126,016
55	IJmuiden Ver I	2027	1000	100	168	77,291
57	IJmuiden Ver II	2028	1000	100	168	77,291
59	IJmuiden Ver III	2029	1000	100	168	86,087
60	IJmuiden Ver IV	2030	1000	100	168	86,087
Total disturbance days resulting from the piling of turbine foundations after 2023						**570,858**
Total disturbance days resulting from the piling of platforms						**70,801**
Total disturbance days resulting from geophysical surveys						**19,738**
TOTAL HARBOUR PORPOISE DISTURBANCE DAYS						**807,969**
Population reduction on the basis of the approximation formula (5% probability)						**865**

5 References

Aarts, G., A.M. von Benda-Beckmann, K. Lucke, H. Özkan Sertlek, R. van Bemmelen, S.C.V. Geelhoed, S. Brasseur, M. Scheidat, F-P.A. Lam, H. Slabbekoorn & R. Kirkwood, 2016. Harbour porpoise movement strategy affects cumulative number of animals acoustically exposed to underwater explosions. Mar. Ecol. Prog. Ser. 557: 261–275.

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. Report TNO-DV 2009 C085.

Binnerts, B., C. de Jong, M. Ainslie, M. Nijhof, R. Müller & E. Jansen, 2016. Validation of the Aquarius models for prediction of marine pile driving sound. TNO report TNO 2016 R11338.

Booth, C., F. Heinis & J. Harwood, 2019. Updating the Interim PCoD Model: Workshop Report – New transfer functions for the effects of disturbance on vital rates in marine mammal species. Report Code SMRUC-BEI-2018-011.

Brandt, M.J., A-C. Dragon, A. Diederichs, M.A. Bellmann, V. Wahl, W. Piper, J. Nabe-Nielsen & G. Nehls, 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. Mar. Ecol. Prog. Ser. 596: 213 – 232.

Buij, R., R. Jongbloed, S. Geelhoed, H. van der Jeugd, E. Klop, S. Lagerveld, H. Limpens, H. Meeuwsen, F. Ottburg, P. Schippers, J. Tamis, J. Verboom, J. T. van der Wal, R. Wegman, E. Winter & A. Schotman, 2018. Kwetsbare soorten voor energie-infrastructuur in Nederland. Wageningen Environmental Research Rapport 2883.

Camphuysen, C.J. & M.L. Siemensma, 2011. Conservation plan for the Harbour Porpoise *Phocoena phocoena* in The Netherlands: towards a favourable conservation status. NIOZ Report 2011-07, Royal Netherlands Institute for Sea Research, Texel.

De Jong, C.A.F., B. Binnerts, M. Prior, M. Colin, M. Ainslie, I. Muller & I. Hartstra, 2018. Wozep – WP2: update of the Aquarius models for marine pile driving sound predictions. TNO Report, TNO 2018 R11671.

Donovan, C., J. Harwood, S. King, C. Booth, B. Caneco, and C. Walker. 2016. Expert elicitation methods in quantifying the consequences of acoustic disturbance from offshore renewable energy developments. Pages 231-237 The Effects of Noise on Aquatic Life II. Springer.

Evans P., J. Waggitt & J. Hiddink, 2018. Mapping cetacean distributions in NW European seas. Marine Ecosystems Research Programme. Presentation ASCOBANS 4th Oct 2018.

Geelhoed, S., M. Scheidat & R. van Bemmelen, 2014. Marine mammal surveys in Dutch waters in 2013. IMARES report C027/14.

Geelhoed, S., M. Scheidat, G. Aarts, R. van Bemmelen, N. Janinhoff, H. Verdaat & R. Witte, 2011. Shortlist Masterplan Wind - Aerial surveys of harbour porpoises on the Dutch Continental Shelf. IMARES report C103/11.

Geelhoed, S.C.V, N. Janinhoff. S. Lagerveld, L.S. Lehnert & J.P. Verdaat, 2018. Marine mammal surveys in Dutch North Sea waters in 2017. Wageningen Marine Research (University & Research centre), WMR report C030/18.

Gilles, A., S. Viquerat, E.A. Becker, K.A. Forney, S.C.V. Geelhoed, J. Haelters, J. Nabe-Nielsen, M. Schiedat, U. Siebert, S. Sveegaard, F.M. van Beest, R. van Bemmelen & G. Aarts, 2016. Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. Ecosphere 7: e01367. 10.1002/ecs2.1367.

Hammond, P.S., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. MacLeod, V. Ridoux, M.B. Santos, M. Scheidat, J. Teilmann, J. Vingada & N. Øien, 2017. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys.

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

Hammond, P.S., P.P. Berggren, H.H. Benke, D.D.L. Borchers, A.A. Collet, M.M.P. Heide Jorgensen, S.S. Heimlich, A.R. Hiby, M.F. Leopold & N. Øien, 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39: 361-376.

Harwood, J., S. King, R. Schick, C. Donovan & C. Booth, 2014a. A protocol for implementing the interim population consequences of disturbance (PCOD) approach: quantifying and assessing the effects of UK

offshore renewable energy developments on marine mammal populations. Report SMRUL-TCE-2013-014. Scottish Marine and Freshwater Science 5(2).
Harwood, J., R. Schick & C. Booth, 2014b. Using the interim PCOD framework to support a cumulative impact assessment in Netherlands waters, report SMRUM-RWS-2014-014 (unpublished).
Heinis F., C.J. de Jong & Werkgroep Onderwatergeluid, 2015. Cumulatieve effecten van impulsief onderwatergeluid op zeezoogdieren. TNO rapport TNO 2015 R10335.
IMMWG – Interagency Marine Mammal Working Group established by UK Statutory Nature Conservation Agencies Chief Scientist Group, 2013. Management units for marine mammals in UK waters.
Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu, 2016a. Kader Ecologie en Cumulatie t.b.v. uitrol windenergie op zee. Deelrapport A: Methodebeschrijving.
Ministerie van Economische Zaken & Ministerie van Infrastructuur en Milieu,, 2016b. Kader Ecologie en Cumulatie t.b.v. uitrol windenergie op zee. Deelrapport B: Beschrijving en beoordeling van cumulatieve effecten bij uitvoering van de Routekaart Windenergie op zee.
Ministerie van Infrastructuur en Milieu, i.s.m. ministerie van Economische Zaken, Landbouw en Innovatie, 2012. Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020,Deel 1
Nielsen, N.H., J. Teilmann, S. Sveegaard, R.G. Hansen, M-H.S. Sinding, R. Dietz & M.P. Heide-Jørgensen, 2018.Oceanic movements, site fidelity and deep diving in harbour porpoises from Greenland show limited similarities to animals from the North Sea.Mar. Ecol. Prog. Ser. 597, 259 – 272.
Scheidat, M., R. Leaper, M. van den Heuvel-Greve & A. Winship, 2013. Setting Maximum Mortality Limits for Harbour Porpoises in Dutch Waters to Achieve Conservation Objectives. Open Journal of Marine Science 2013, 3.
Verfuss, U.K., C.E. Sparling & C.G. Booth, 2014. Does noise mitigation matter? Population consequences of piling noise on marine mammals. Presentation at the IMCC Noise Workshop, Glasgow, 13th August.

Annex 1: Derivation of standards comparable with 2015 KEC

To derive a provisional set of sound standards for the wind energy areas Hollandse Kust (west), Ten Noorden van de Waddeneilanden and IJmuiden Ver that can be used in the calculations, the same permitted reduction in the harbour porpoise population per installed capacity was assumed as for the wind farms in the Energy Agreement. This means that, if the effects were to be calculated in the same way (in other words, with iPCoD 2.1), the application of the sound standards for the wind farms planned under the Energy Agreement combined with those of the three new wind energy areas will result in effects such that the ecological standard of a maximum reduction of 5% in the Dutch population will be exceeded since the maximum permitted population reduction of 5% has been adopted as the underlying principle for the calculation of the sound standards for the ten wind farms in the Energy Agreement.

However, it is expected that, because of the incorporation of the new insights in the stages of the staged procedure, the results of the calculations will turn out differently and the calculated reduction in the Dutch harbour porpoise population is likely to be smaller. Definitive sound standards for the new farms can be derived only once a picture has been established of the effects of applying the current sound standards in the calculations.

Annex Table 1-1 shows the maximum permissible reduction per wind energy area if the same permissible reduction in the harbour porpoise population per installed capacity is assumed.

Annex Table 1-1 Maximum permissible reduction in the harbour porpoise population assumed in the calculations for the planned wind farms on the DCS in the 2018 KEC.

Wind farm/site	**Size**	**Max. permissible reduction in harbour porpoise population (n)**
Borssele I/II	752 MW: 2 x 47 x 8 MW	510
Borssele III/IV	731.5 MW: (40 + 37) x 9,5 MW	510
Hollandse Kust (south) I/II	752 MW: 2 x 47 x 8 MW	510
Hollandse Kust (south) III/IV	752 MW: 2 x 47 x 8 MW	510
Hollandse Kust (north) V	760 MW: 95 x 8 MW	510
Hollandse Kust (west) VI/VII	1,520 MW: 2 x 76 x 10 MW	2 x 510
North of Wadden	760 MW: 76 x 10 MW	510
IJmuiden Ver	4,000 MW: 400 x 10 MW	2684 (= 4,000/760 x 510) = 4 x 671

To derive the provisional sound standards used for the iPCoD calculations for the three new energy areas, the method used for the wind energy areas in the Energy Agreement was followed as closely as possible. The following assumptions were made:

- Sound standard derived on the basis of the contours[7] calculated with Aquarius 4.0 given a threshold value for the disturbance of harbour porpoises at broadband SELss = 140 dB re 1 μPa^2s.
- Disturbance contours were calculated for a piling energy of 2,000 kJ and for pile-driving with a SELss(750 m) sound standard of 160 to 180 dB re 1 μPa^2s with steps of 1 dB.
- The reduction of the harbour porpoise population resulting from the different scenarios was calculated using the approximation formula for the relationship between the number of harbour porpoise disturbance days and population reduction (Heinis & de Jong, 2015). The following data were used in the calculation of harbour porpoise density and the size of the vulnerable sub-population:
    - Density of harbour porpoises for Hollandse Kust (west) and IJmuiden Ver as for Hollandse Kust (north), i.e. spring: 1.174; summer: 0.65; autumn: 0.398. The wind energy area Ten Noorden van de Waddeneilanden is not located in the area D designated by Geelhoed et al. (2011, 2013, 2015) but in

[7] The disturbance areas calculated with Aquarius 4.0 that were used to derive the provisional sound standards included a calculation error: the pile diameter was entered rather than the radius. This error was corrected before the final calculations were carried out with iPCoD but the provisional sound standards had already been derived and processed by that time. The difference works out differently for each location but the disturbance area assumed for the derivation of the provisional sound standard for the location North of the Wadden Islands was too small. Since the sole purpose of these calculations was to calculate a situation for the 'new' wind farms that was more or less comparable with the wind farms in the Energy Agreement, it was decided not to derive the provisional standards again.

area C. The densities derived for the 2018 KEC were assumedhere: spring: 0.812; summer: 0.785; autumn: 0.500.
    - Vulnerable sub-population: 30,000 for the Dutch coast (west) and IJmuiden Ver (cf. 2015 KEC) and 20,000 for Ten Noorden van de Waddeneilanden (highly variable over the years, but this is more or less an upper limit of the estimate for area C from Geelhoed et al. 2011, 2013, 2015).
- Depending on the number of wind turbines installed and the densities of harbour porpoises found on the DCS (season), the sound standard was set so that the defined acceptable margin was not exceeded (see Annex Table 1-1).
- In the case of wind energy areas with several sites (Hollandse Kust (west) and IJmuiden Ver), the sound standard was calculated on the basis of the site (or set of sites) with the largest disturbance contours and therefore the largest effects. One given set of standards applies in one given wind energy area.
- In order to ensure that work is not stopped immediately for the purposes of enforcement in the event of the sound standard being exceeded, the standard derived on the basis of the predicted effects was made 1 dB stricter. It has emerged that, in practice, it is particularly difficult to comply immediately with the standard for the first piles. Because of the selected approach, the work does not have to be stopped if the defined margin is not exceeded and permissible limits are not exceeded.

The following Annex Table 1-2 lists the standards calculated for wind energy areas 2016 - 2030 on the basis of the above underlying assumptions. The level of the sound standard depends on the season in which the pile-driving takes place. However, this was not taken into account in the calculations for the 2018 KEC and (for the time being) the strictest standard for each wind energy area was used. This also applies to the existing sound standards for the wind energy areas in the Energy Agreement: Borssele, Hollandse Kust (south) and Hollandse Kust (north).

Annex Table 1-2 Standard for piling sound for wind energy areas in the period leading up to 2030 that were used in the calculations. These calculations assumed the same permissible reduction in the harbour porpoise population per installed capacity as in the 2015 KEC. Sound standards used in the calculations are shown in bold. Blue: sound standards adopted in site decisions.

Wind energy area	**Maximum sound burden (dB re 1 µPa^{2}s at 750 m)**		
	Spring	**Summer**	**Autumn**
Borssele I/II	**163**	169	171
Borssele III/IV	**163**	169	171
Hollandse Kust (south) I/II	**165**	171	173
Hollandse Kust (south) III/IV	**165**	171	173
Hollandse Kust (north) V	**165**	169	172
Hollandse Kust (west) VI/VII	**165**	169	173
Ten Noorden van de Waddeneilanden	**167**	167	170
IJmuiden Ver	**165**	169	172

Annex 2: Modelling piling sound

The underwater sound propagation for driving a representative foundation pile (turbine and platform) was calculated for each location. Sound propagation depends on:

- type of hammer, mass of the hammer and hammer strike energy
- anvil mass and contact stiffness
- diameter, wall thickness and material of the pile
- length of the pile in the water and in the bed
- mitigation measure (bubble screen, mantle, etc, …)
- water depth (bathymetry) around the pile
- bed properties around the pile (density, sound velocity and absorption)
- wind speed/wave height

In recent years, TNO has developed a suite of Aquarius computing models to calculate underwater sound propagation around a pile. The model version selected from that suite depends on the available information and the complexity of the calculation (number of variations to be calculated). The uncertainty in the calculated sound propagation should, in theory, decrease when more detailed information is available. The models have been validated to only a limited extent (PAWP, Luchterduinen, Gemini) and the results of those studies show that we are not yet in a good position to quantify this uncertainty because we cannot adequately distinguish between the contributions of the various parameters (see the list above) to uncertainty.

- For the piling sound calculations in this study, the Aquarius 4 model was used that was further developed in the context of WOZEP, see de Jong et al. (2018).
- The Aquarius 4 model calculations result in a sound propagation in terms of the third band spectrum of the SELss in the vicinity of the pile as a function of distance and depth.
- As a measure for quantifying the possible disturbance of harbour porpoises, we use, in accordance with the KEC staged procedure from 2015, the unweighted broadband value for the calculated SELss.
- We select the maximum value of the SELss over the water depth[8]. In Aquarius 4, the SELss as a function of depth is calculated in 10 equidistant steps and the maximum is then selected.

Hammer

Hammer type and energy are selected at a late stage of the design process. For this study it is assumed, at the request of Rijkswaterstaat, that, in all cases, the wind turbines are placed on monopile foundations that are struck with an estimated maximum hammer energy of 2000 kJ. Turbine capacity is expected to increase over the years. A maximum hammer energy of 4000 kJ is assumed for the piling of the monopiles for turbines larger than 12 MW. The largest hammer currently used by IHC delivers 4000 kJ (maximum pile diameter 7.5 m). On the basis of information provided by TenneT, a hammer energy of 2000 kJ is also assumed for the driving of the smaller piles (2-3m) for the jacket foundations of the platforms.

The Aquarius 4 model uses an idealised model of the hammer (Deeks & Randolph 1994) that requires data about the kinetic energy of the hammer, the hammer and anvil masses and the contact stiffness between the hammer and anvil. An analysis of all possible hammer types will not be included in the present study due to the lack of sufficiently detailed data. The hammer (IHC S-2000) used for Gemini was adopted as the starting point for determining the ultimate parameters:

- Turbines of 12 MW or less: pile diameter D = 5.5 m, 2000 kJ hammer energy
- Turbines of 15 MW: pile diameter D = 7.5 m, 4000 kJ hammer energy
- Platform piles: pile diameter D = 3 m, 2000 kJ hammer energy

Other parameters:

[8] In Aquarius 1, this was a good match for the value at 1 m above the bed.

- Monopile wall thickness (API formula): $t = 0.01D + 6.35e^{-3}$ m
- Anvil mass = ram mass = hammer energy * (1 ton/20 kJ)
- Contact stiffness 20 GN/m

Mitigation

In various countries (DK, NL, BE), a sound standard will be used in the coming years for pile-driving, usually in terms of a maximum permissible unweighted broadband SELss at a distance of 750 m from the pile.

It will be left to the builders to determine how they will meet this standard. The modelling will therefore not be based on a specific solution: the calculated sound propagation (SELss) for unmitigated pile-driving will be reduced by a constant value so that it just complies with the sound standard at 750 m from the pile.

- DK: sound standard SEL(750m)= 160 dB
- BE standard Lzp(750m)=185 dB (according to “Omschrijving van Goede Milieutoestand & vaststelling van Milieudoelen voor de Belgische mariene wateren”, http://www.vliz.be/en/imis?module=ref&refid=220232), which is based on Lippert et al. 2015 “Empirical estimation of peak pressure level from sound exposure level. Part II: Offshore impact pile driving noise” (JASA 138(3)) and data from Luchterduinen and Gemini, which can be stated in global terms as a standard where SEL(750m)=160 dB.
- NL standard SEL(750) per wind energy area, as adopted in site decisions and calculated in the same way (using the approximation formula from the KEC report for the relationship between harbour porpoise disturbance days and population decline) for the farms dating from after the SER agreement.

Because the builders are free to choose the measures they implement to comply with the sound standard, the sound standard is processed in the Aquarius calculations on the basis of the calculated sound distribution for unmitigated pile-driving. A constant value was subtracted from this sound distribution (unweighted broadband SELss) for each project that ensures that the SELss (maximum value over the water depth) at 750 m from the pile is less than or equal to the sound standard in all directions. Any effect on the shape of the spectrum as a result of the selected mitigation measure is therefore not included in the calculations.

Locations

The scenarios provided by Rijkswaterstaat state a central location for each planned farm. This does not necessarily result in a realistic worst case for the calculated disturbance area. That worst case will generally be seen at the greatest depth in the farm and at the largest distance offshore. For each farm, therefore, a 'realistic worst-case' location in the vicinity of the given central point was selected on the basis of the bathymetry.

Sediment

In the Aquarius models, the sediment is modelled as an equivalent uniform liquid (without shear stiffness or layers). The WOZEP study has shown that this assumption results at low frequencies in a good match with the U8 measurement data provided that a frequency-dependent absorption in the sediment is taken into account. The following choices were made:

- ‘Medium sand' parameter values (Ainslie 2010, table 4.18)$\rho = 2086\ kg/\mathrm{m}^3, c = 1797\ m/s$, and $\alpha = 0.88\ dB/\lambda$ at a sound velocity in the water of 1500 m/s.
- Decreasing absorption ($\sim f^{1.8}$) below 250 Hz

Wind

Because of uncertainty about the reliability of the modelling of the extra propagation loss resulting from the disturbance of the water surface by wind and waves, it has been decided to adopt a cautious approach and omit this effect from the Aquarius 4 calculations, in other words to assume a wind speed of 0 m/s.

- In 2015, the average of the disturbance area calculated with Aquarius 1 with and without wind losses was adopted. It was later found that the model for wind losses in Aquarius 1 was particularly useful to compensate for the mistake made by selecting a point-source model.

- In the new Aquarius 4 version, this is no longer necessary and we adopt the contours for calculations without wind.

Transformer platforms

In consultation with Rijkswaterstaat, pile-driving for the transformer platforms was included for the Dutch farms only.

- two jacket piles a day on average
- hammer energy 2000 kJ
- construction of the platforms one year before the piling for the turbine foundations

Annex 3: Modelling geophysical surveys

Annex 3.1 Scenario description

Geophysical surveys are conducted over a period of time of several (1-5) years prior to the construction of a wind farm in order to map out the bed structure in different layers and to determine whether any unexploded ordnance is present. These surveys cover both the piling area (turbines and platforms) and the route along which the cables are laid to land.

The scenario for the geophysical survey consists of four sub-scenarios:

1) Global survey of the area of the future wind farm
2) Detailed survey of the locations of the future turbines, platforms and infield cables
3) Global survey of the cable route
4) Detailed survey of the cable route

1) Global survey of the area of the future wind farm
Underlying assumptions:

- A geophysical survey covers about 10 km^2 per day and it continues 24 hours a day (unless there is bad weather and during the monthly crew changeover, which we ignore in this study). The number of days per farm = surface covered by geophysical survey divided by 10 km^2.
- We assume that this survey will be conducted in the five years prior to the construction of the farm.
- The work is done with a multibeam, a sidescan sonar, a magnetometer, a sub-bottom profiler and a multi-channel sparker. Here, we assume the use of a sparker as a worst-case scenario, which leads to effect distances of 3 km.
- We do not perform location-specific acoustic calculations, and assume that 10 km^2 is scanned a day, with an estimated maximum disturbance distance (sparker) of ~3 km. For a rectangular scanning area, that results in a disturbance area of ~84 km^2 a day.

2) Detailed survey of the locations of the future turbines, platforms and infield cables
Underlying assumptions:

- Typically carried out 1 to 2 years before the construction of the farm (in line with Gemini). We assume one year before construction.
- The same assumptions otherwise as for the Global surveys (1)

3) Global survey of the cable route
Underlying assumptions:

- This is a survey of the route from the wind energy area to land. In addition, a survey of the location of the platform(s) is planned, in particular for obstacles (sidescan sonar, bathymetry) and magnetic contacts (unexploded ordnance, also known as UXO).
- The total surveyed area is estimated as the number of kilometres of cable multiplied by a strip width. This width depends on the number of cables and distance to the farm (estimated values in Table 3).
- Typically performed two years before the global survey.
- This survey involves the use of a magnetometer, sidescan sonar, sub-bottom profiler, singlebeam and multibeam echo sounder. A multi-channel sparker may not be needed if the sub-bottom profiler can provide enough information down to the burial depth of the cables (1 - 2 meters) plus the height of the sand waves (location-specific) and it is not included here because very deep bed penetration is not required.
- We use an effect distance here for the typical distance of 1 km for the sub-bottom profiler (see Annex Table 3-4).

We do not perform location-specific acoustic calculations and assume that 10 km^2 is scanned a day, with an estimated maximum disturbance distance (sub-bottom profiler) of ~1 km. For a rectangular scanning area, this results in a disturbance area of ~30-36 km2 area per day (depending on the route).

4) Detailed survey of the cable route

Underlying assumptions:

- The route from the search area to land is estimated as the number of km of the route multiplied by a strip around the cable (approximately 100 meters around the cable).
- This survey is conducted one year before the construction of the turbines using a magnetometer, sidescan sonar, sub-bottom profiler, singlebeam and multibeam echo sounder because very deep bed penetration is not required. Here we use an effect distance for the typical distance of 1 km for the sub-bottom profiler (see Annex Table 3-4). Limited penetration is needed for the largest area; deeper penetration is needed in the order of 10 metres between the coast and the 3 km line only.
- We do not perform location-specific acoustic calculations and assume that 10 km^2 is scanned a day, with an estimated maximum disturbance distance (sub-bottom profiler) of ~1 km. Any effect of sparker deployment in the last 3 km, the coast and in and around the vicinity of the platforms is neglected. For a rectangular scanning area, this results in a disturbance area of ~30-36 km2 area per day (depending on the route).

The above scenarios lead to the following conclusions for each farm (Annex Table 3-1) and platform/cable route (Annex Table 3-2):

Annex Table 3-1 Geophysical survey by farm

Timetable	Activity	Disturbance area per day/km^2
5 years before construction	Global survey area wind farm and platforms	84
1 year before construction	Detailed survey of the locations of the future turbines and platforms	84

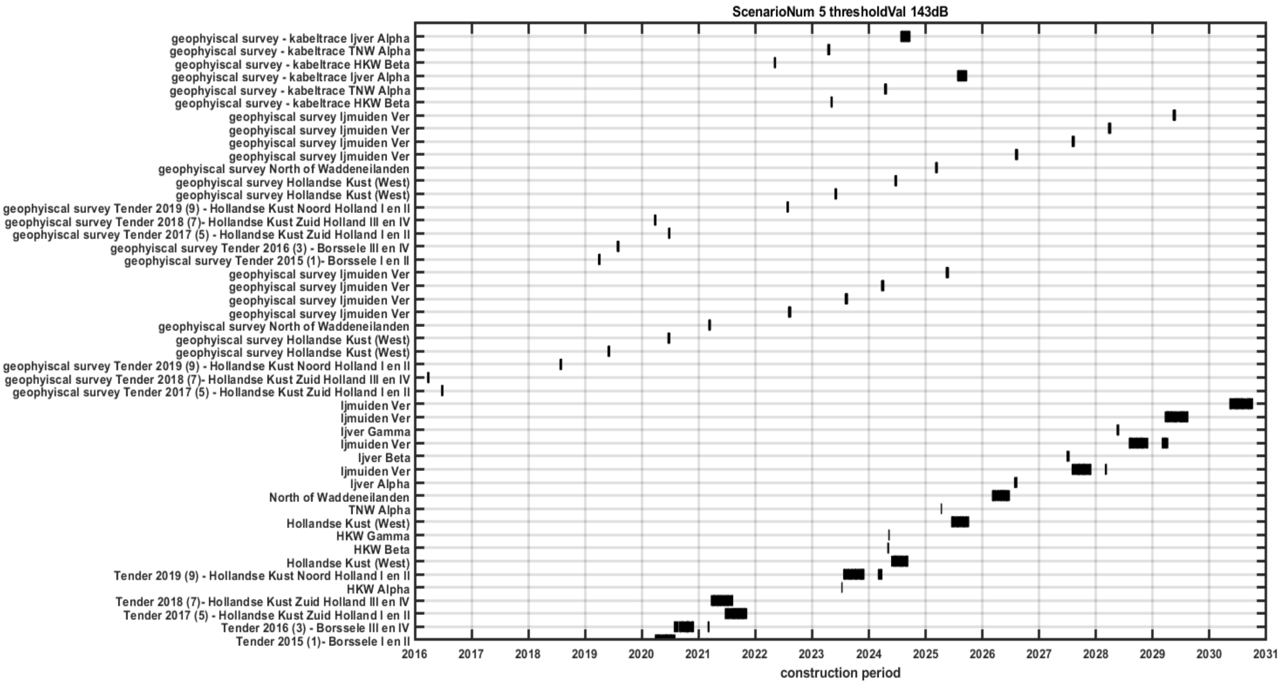
Annex table 3-2 Geophysical survey by cable route

Timetable	Activity	Disturbance area per day/km^2
2 years before construction	Global survey of the cable route	Depending on cable route to farm (30 - 36)
1 year before construction	Detailed survey of the cable route	Depending on cable route to farm (30 - 36)

Estimates for the cable routes depend on the distance to land and the type of cable connection (AC or DC). The values used here are stated below in Annex Table 3-3.

Annex Table 3-3 Estimated value for distances from transformer platforms to land and associated geophysical survey of the cable route. The assumed values for disturbance area and number of survey days are also given.

Transformer platform	Length of route to land /km (estimate)	Route width/km (estimate)	Surface of route/km^2	Number of km^2 surveyed per day	Number of survey days	Disturbance area per day/km2	Density in spring (ind/km^2)	harbour porpoise disturbance days
Hollandse Kust West beta	75	1.2 (2 cables)	90	10	9	33	0,721	214
North of Wadden alpha	120	1.2 (2 cables)	144	10	14.4	33	0.785	373
IJmuiden Ver alpha, beta, gamma	200 x 3 (cables)	1	600	10	60	36	0.698	1507



Annex Figure 3-1 Calendar of impulse days in the period 2016 - 2030 according to scenario 5 (Dutch wind farms, platforms and surveys)

Annex 3.2 Estimation of effect distances with different geophysical instruments

Geotechnical surveys are carried out in preparation for the construction of the wind farms with various acoustic sources such as multibeam and side-scan sonars, bottom profilers and sparkers.
The source level and frequency range of the survey signals are very different from those of piling sound. On the basis of global information about the acoustic sources in combination with a threshold value weighted by the frequency sensitivity of harbour porpoise hearing, an estimate was made of the disturbance distance for different types of systems used in these surveys (Annex Table 3-4).

Annex Table 3-4 Typical systems used during geophysical surveys for the construction of wind farms, platforms and cable routes. The third column provides an estimate of disturbance distances for the different types of system.

System type	**System example**	**Estimated effect distance**
Multibeam echo sounder:	Kongsberg EM2040 Dual Head, Dual Swath / Dual Ping – Frequency 400 kHz	Above harbour porpoise hearing threshold; No significant sub-harmonics; Expected effect distances small (and negligible);
Sidescan sonar:	Edgetech 4200 300/600 – Frequency: 239 kHz (LF) and 555 kHZ (HF)	Above harbour porpoise hearing threshold; No significant sub-harmonics. Expected effect distances small (and negligible);
Sub-Bottom Profiler: Magnetometer: Geomatrix G882 Cesium vapour magnetometer	Innomar SES 2000 Standard parametric sub-bottom profiler – Power: > 50kW; Frequency: 8 - 100 kHz	Expected effect distances between 1 and 2 km (caused by primary frequency of the source at 100 kHz; see Annex Figure 3-2)
Sparker Single-channel	GSO 200-tip sparker (assumed operated at 500 J)	Expected effect distances between 1 and 2 km (based on estimates; see Annex Figure 3-2)
Sparker Multi-channel	GSO 360-tip Sparker seismic source + 2000 J PSU (operated at 900 J)	Expected effect distances between 3 and 4 km (based on estimates; see Annex Figure 3-2)

The assumptions for the estimates of disturbance distances for harbour porpoises are looked at in further detail in the following sections and summarised in Annex Table 3-4.

Acoustic characteristics of geophysical surveys:
The echo sounders used during geophysical surveys are high-frequency (> 200 kHz) and probably not audible to harbour porpoises. Measurements of this type of system seem to indicate that hardly any acoustic energy is propagated at lower frequencies (e.g. Crocker et al. 2018).

The sources that cause significant sound levels at frequencies audible to harbour porpoises are the sub-bottom profilers and sparkers.

A sub-bottom profiler that is typically used, a 'parametric sub-bottom profiler', generates low-frequency (~10 kHz) sound by simultaneously emitting more high-frequency (~100 kHz) sounds. Using high frequencies results in a very directional, downward, low-frequency beam (~3-6 degrees -3 dB beam width). Leaflets from suppliers of parametric sub-bottom profiler providers indicate that the source level (SL) is in the main frequencies range (85 - 125 kHz) > 240 dB re 1 µPa·m. The source levels at the low frequencies are around 202 dB re 1 µPa·m. This corresponds to a typical 30-40 dB reduction in the source level of the secondary frequencies in a parametric sonar (P. Bears, pers. comm.). A typical SL = 240 dB re 1 µPa·m at 100 kHz is assumed here for the estimation of the effect distances. For the secondary frequencies, an SL = 202 dB re 1 1 µPa·m is assumed at 10 kHz. Typical pulse lengths for the sub-bottom profiler are in the order of t_{pulse} ~ 0.04 - 30 ms. This is based on a source level energy (SLE) in the main beam of SL + 10*log10(t_{puls} / 1s) dB ~ 187 dB re 1 $µPa^2·m^2·s$. For the horizontally propagated sound (which is propagated effectively and can result in disturbance), another 60 dB is subtracted here because of the high directionality of this source.

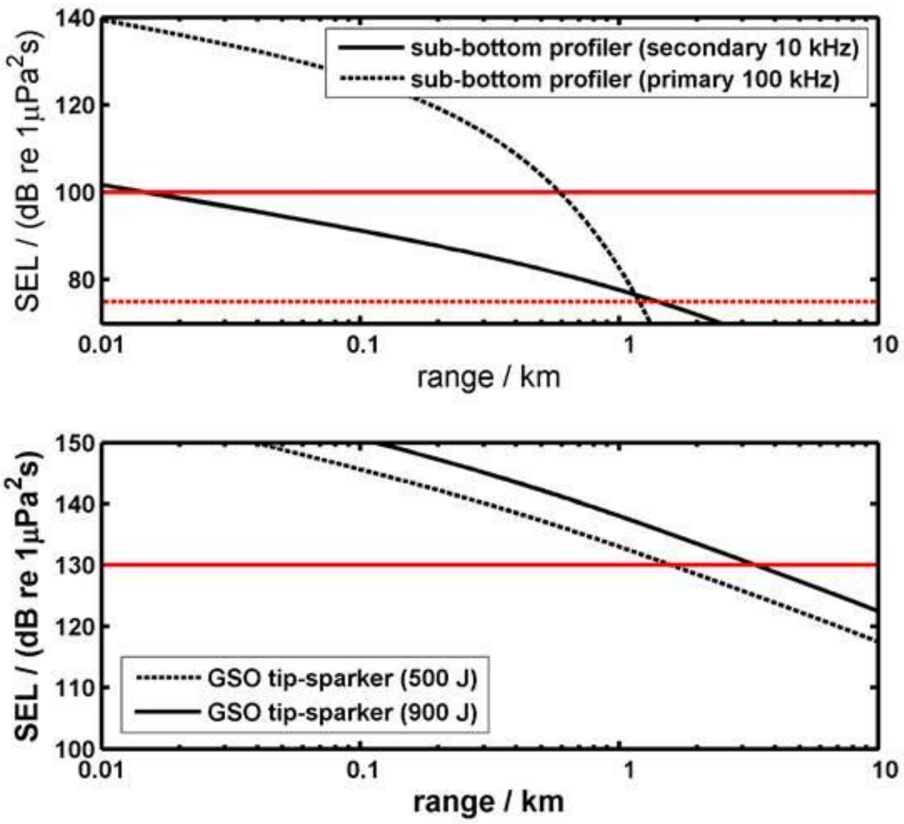
Sparkers are systems that generate air bubbles by means of electrical discharges to 'tips'. This produces an air bubble, which generates a broadband impulse sound, typically with higher frequencies than the airguns often used for seismic surveys. Typical source levels can be found in Crocker et al. (2018) and they depend on the power used: SLE ~ 167-181 dB re 1 $µPa^2m^2s$ (500 J) and ESL ~ 179-186 dB re 1 $µPa^2m^2s$ (900 J). This analysis is based on the maximum values stated. The bandwidths of the generated pulse are BW_{-3dB} ~ 1.2-1.9 kHz (500 J), and BW ~ 3.2 kHz (1000 J) (Crocker et al. 2018). These signals are roughly approximated in the calculations below by assuming a signal of 1 kHz with the above SLE. We assume that directionality is comparable with a single airgun pulse.

Threshold values for the disturbance of behaviour were derived from a review of disturbance thresholds conducted for WOZEP (de Jong & von Benda-Beckmann 2017) and they are summarised for three frequencies used here in Annex Table 3-5.

Annex Table 3-5 SELss threshold values used to estimate effect distances for harbour porpoise disturbance for higher-frequency sources than pile-driving.

Frequency / kHz	**SELss / dB re 1 $µPa^2s$**
1	130
10	100
100	75

The propagation loss for these sources in the North Sea is estimated on the basis of a cylindrical regime and the 'mode-stripping' regimes for a point source (cf. 9.46 in Ainslie 2010), with values that are representative for a sandy bed (which are typical for the North Sea) (Annex Figure 3-2). The distances corresponding to the disturbance thresholds in Annex Table 3-5 are shown in Annex Figure 3-2 and summarised in Annex Table 3-4.



Annex Figure 3-2 Single pulse SEL (black lines) as a function of distance to the source for a parametric sub-bottom profiler with the primary frequency (dashed line) and secondary frequency (upper panel) and two types of sparker (lower panel). The red lines show the frequency-dependent harbour porpoise disturbance thresholds (from Annex Table 3-5).

References

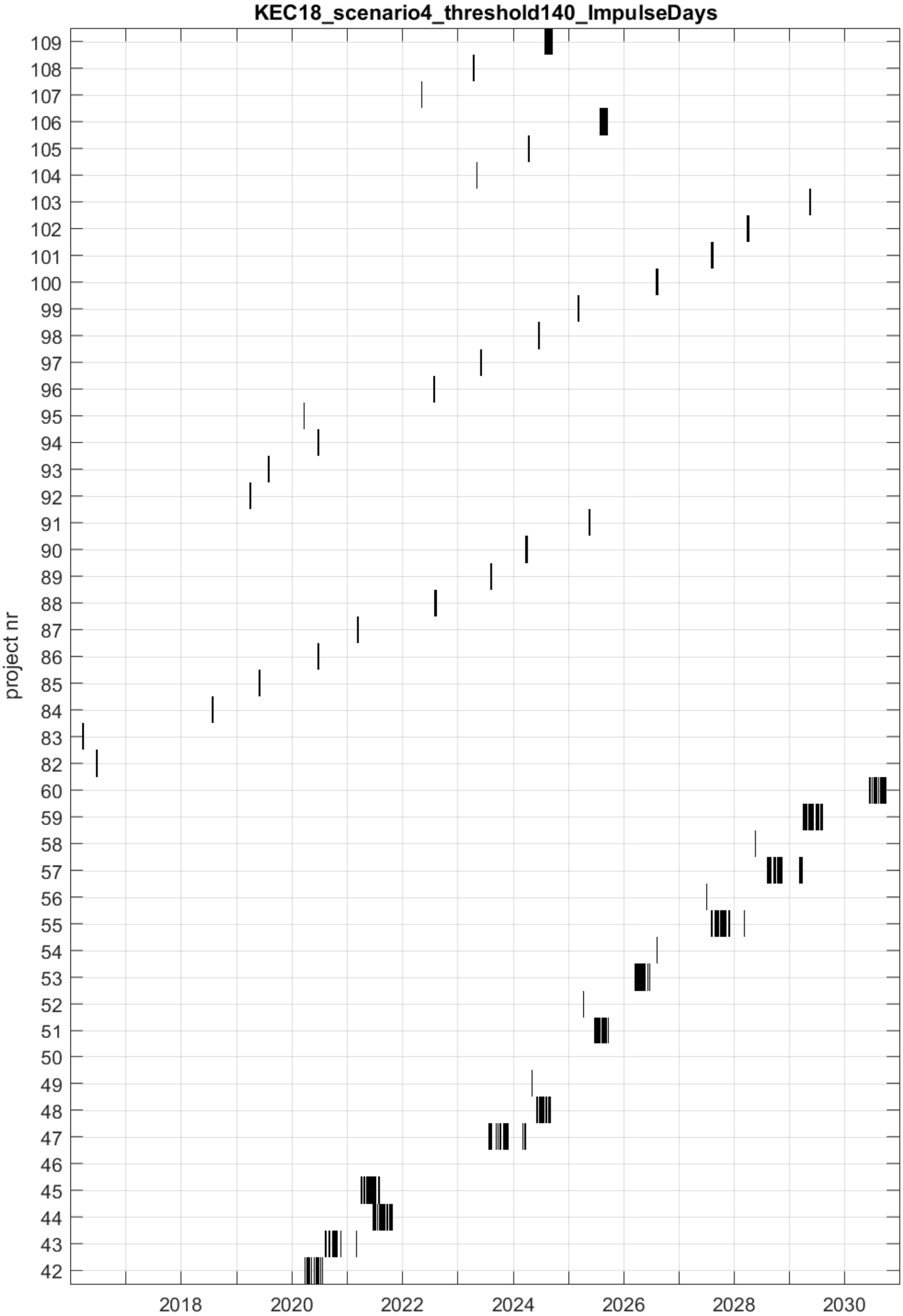
Crocker, S.E. Fratantonio, F.D., Hart, P.E., Foster, D.S., O'Brien, T.F. & S. Labak (2018). Measurement of Sounds Emitted by Certain High-Resolution Geophysical, Survey Systems IEEE JOURNAL OF OCEANIC ENGINEERING 99, 1-18, 10.1109/JOE.2018.2829958.

De Jong, C. & S. von Benda-Beckmann (2017). Wozep underwater sound: frequency sensitivity of porpoises and seals, TNO Report TNO 2017 R11238, 1-53.

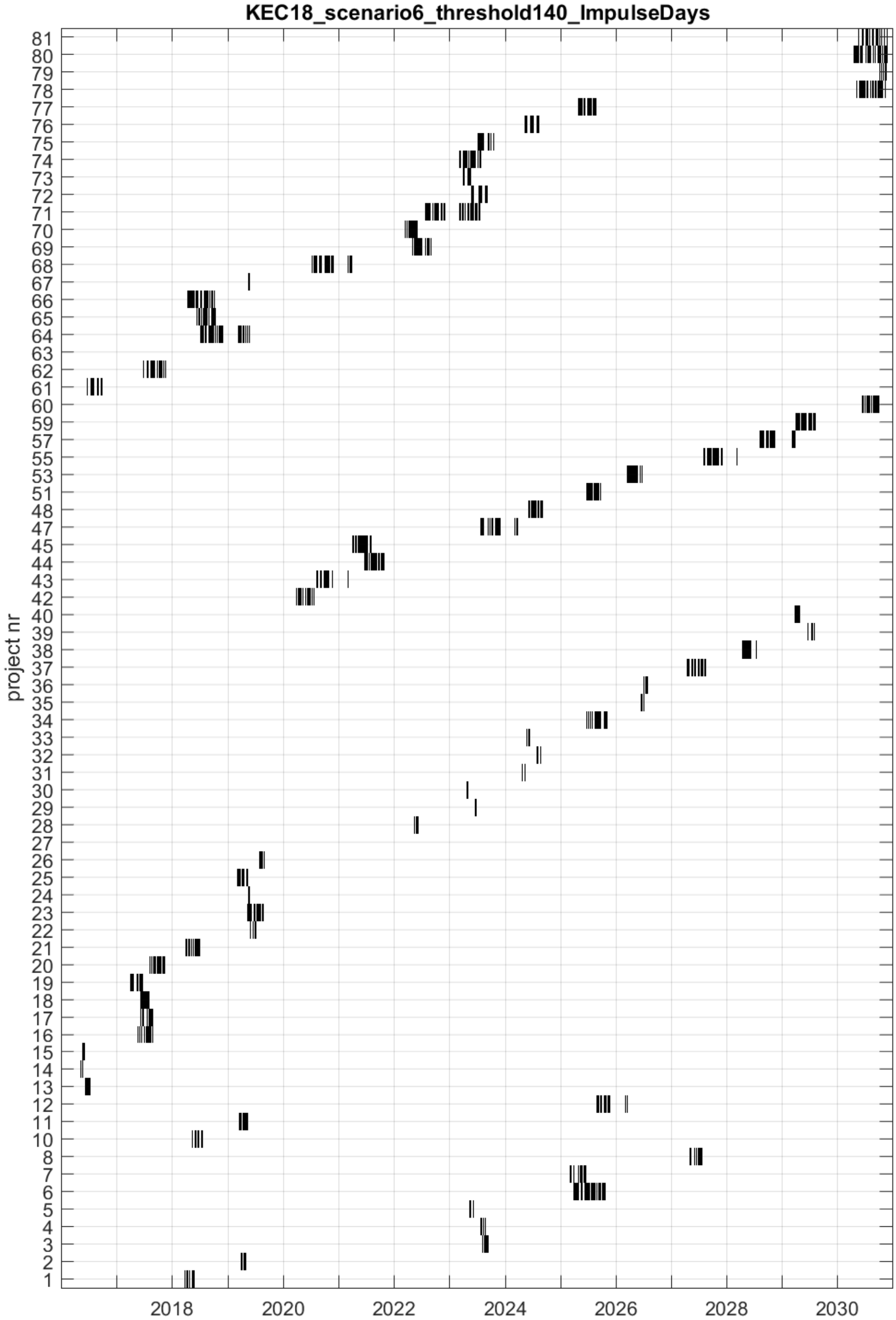
Annex 4: Scenarios

id	Name	Country	Expected start of offshore construction	Capacity in MW (Max)	MW Turbine	Estimated number of piles (max capacity/MW Turbine)
1	Rentel	Belgium	2018	309	7	44
2	Norther	Belgium	2019	230	8	29
3	Seastar	Belgium	2023	246	8	31
4	Mermaid	Belgium	2023	246	8	31
5	Northwester	Belgium	2023	224	9.5	24
6	Mermaid	Belgium	2025	1500	10	150
7	Fairy Bank 1	Belgium	2025	700	10	70
8	Fairy Bank 2	Belgium	2027	700	12	58
9	Fairy Bank 3, N2000	Belgium	2030	700	15	47
10	Horns Rev 3	Denmark	2018	400	8	50
11	Vesterhavet Nord/Syd	Denmark	2019	344	8	43
12	Tender 2019	Denmark	2025	800	10	80
13	NOR 0-1 Riffgat	Germany	2016	108	3.6	30
14	NOR 2-1 Alpha ventus	Germany	2016	62	5	12
15	NOR 0-2 Nordergründe	Germany	2016	111	6	19
16	Sandbank (ID N-5.3)	Germany	2017	288	4	72
17	Gode Wind 01 (ID N-3.1)	Germany	2017	330	6	55
18	Gode Wind 02 (ID N-3.2)	Germany	2017	252	6	42
19	Nordsee One (ID N-3.3)	Germany	2017	332	6	55
20	Veja Mate (ID N-6.2)	Germany	2017	402	6	67
21	Merkur Offshore (ID N-2.6)	Germany	2018	396	6	66
22	Trianel Wind Farm Borkum Bauphase 2 (ID N-2.3)	Germany	2019	200	6	33
23	EnBW Hohe See (ID N-8.2)	Germany	2019	497	7	71
24	Albatros (ID N-8.3)	Germany	2019	112	7	16
25	Borkum Riffgrund II (ID N-2.5)	Germany	2019	448	8	56
26	Deutsche Bucht (ID N-6.3)	Germany	2019	260	8.4	31
27	Deutsche Bucht Pilot (ID N-6.3-P)	Germany	2019	17	8.4	2
28	KASKASI II (ID N-4.4)	Germany	2022	325	10	33
29	Gode Wind III (ID N-3.4)	Germany	2023	110	10	11
30	Gode Wind 04 (ID N-3.7)	Germany	2023	132	10	13
31	OWF West (ID N-1.1)	Germany	2024	240	10	24
32	Borkum Riffgrund West II (ID N-1.2)	Germany	2024	240	10	24
33	Borkum Riffgrund West I (ID N-1.3)	Germany	2024	240	10	24
34	EnBW He dreiht (ID N-7.1)	Germany	2025	900	10	90
35	N-3.7 (except Gode Wind 04)	Germany	2026	230	12	19

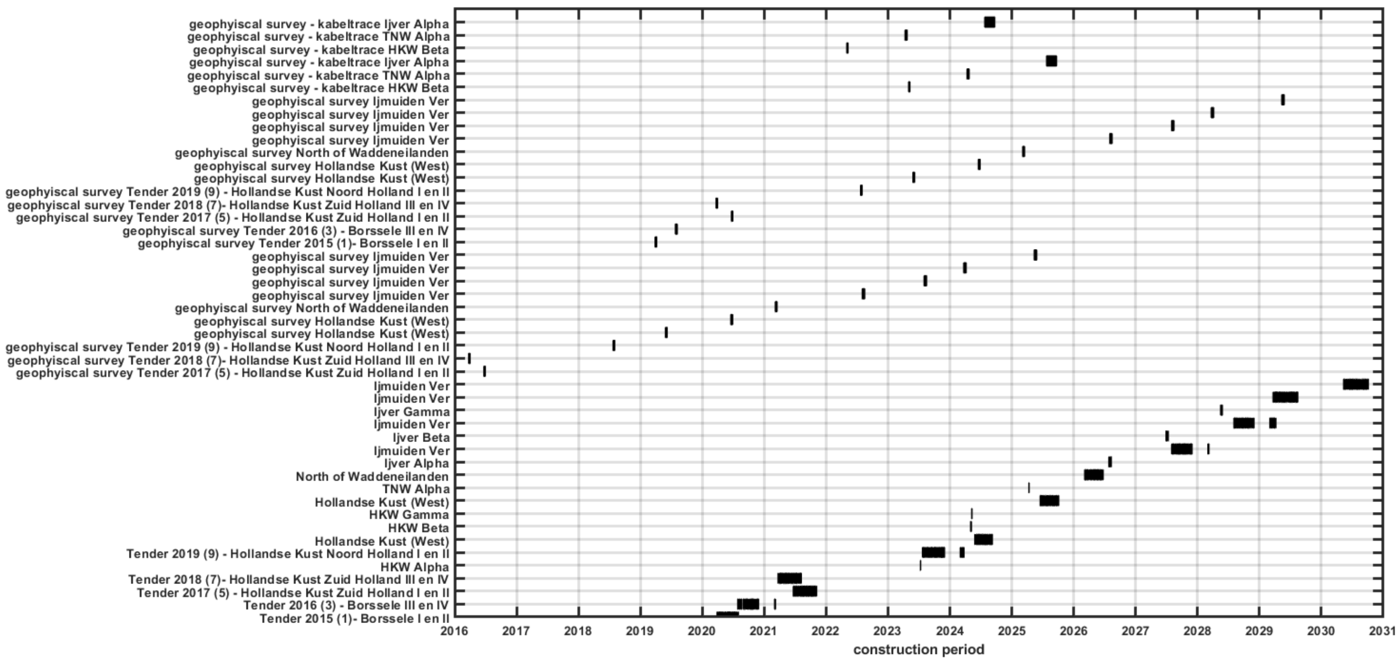
36	N-3.8	Germany	2026	350	12	29
37	N-7.2	Germany	2027	900	10	90
38	N-3.6	Germany	2028	750	12	63
39	N-3.5	Germany	2029	300	12	25
40	N-6.7	Germany	2029	280	12	23
41	N-6.6	Germany	2030	670	15	45
42	Tender 2015 (1)- Borssele I and II	Netherlands	2020	752	8	94
43	Tender 2016 (3) - Borssele III and IV	Netherlands	2020	752	9.5	79
44	Tender 2017 (5) – Hollandse Kust South I and II	Netherlands	2021	752	8	94
45	Tender 2018)- Hollandse Kust South III and IV	Netherlands	2021	752	8	94
46	Hollandse Kust West Alpha Platform	Netherlands	2023	1040	0	6
47	Tender 2019) – Hollandse Kust North I and II	Netherlands	2023	760	8	95
48	Hollandse Kust (West)	Netherlands	2024	760	10	76
49	Hollandse Kust West Beta Platform	Netherlands	2024	1040	0	6
50	Hollandse Kust West Gamma Platform	Netherlands	2024	1040	0	6
51	Hollandse Kust (West)	Netherlands	2025	760	10	76
52	North of Wadden Alpha Platform	Netherlands	2025	1040	0	6
53	Ten Noorden van de Waddeneilanden	Netherlands	2026	760	10	76
54	IJmuiden Ver Alpha Platform	Netherlands	2026	2200-2600	0	18
55	IJmuiden Ver	Netherlands	2027	1000	10	100
56	IJmuiden Ver Beta Platform	Netherlands	2027	2200-2600	0	18
57	IJmuiden Ver	Netherlands	2028	1000	10	100
58	IJmuiden Ver Gamma Platform	Netherlands	2028	2200-2600	0	18
59	IJmuiden Ver	Netherlands	2029	1000	10	100
60	IJmuiden Ver	Netherlands	2030	1000	10	100
61	Dudgeon	UK	2016	402	6	67
62	Thanet	UK	2017	300	3	100
63	Hywind Scotland Pilot Farm	UK	2017	30	6	5
64	Hornsea Project One	UK	2018	1218	7	174
65	East Anglia 1	UK	2018	714	7	102
66	Inch Cape	UK	2018	784	7	131
67	Kincardine	UK	2019	50	8.4	6
68	MORL - Stevenson, Telford, Macoll (Moray)	UK	2020	1100	10	110
69	Beatrice BOWL	UK	2022	588	7	84
70	Neart na Gaoithe	UK	2022	448	8	56
71	Hornsea Project Two	UK	2022	1386	8	173
72	Repsol - Inchcape	UK	2023	784	10	78
73	Thanet extension	UK	2023	340	10	34
74	Seagreen - Alpha and Bravo	UK	2023	1050	10	105
75	MORAY West	UK	2023	750	10	75
76	East Anglia 2	UK	2024	800	10	80
77	East Anglia 1 North	UK	2025	800	10	80
78	Hornsea Project Three	UK	2030	2400	8	300
79	East Anglia 3	UK	2030	1200	8	150
80	Norfolk Vanguard	UK	2030	1800	10	180
81	Norfolk Boreas	UK	2030	1800	10	180



Calendar of impulse days based on scenario 4 (Dutch wind farms, platforms and surveys)



Calendar of impulse days based on scenario 6 (International wind farms)



Calendar of impulse days in the period 2016 - 2030 based on scenario 5 (Dutch wind farms, platforms and surveys)

Annex 5: Disturbance areas and harbour porpoise disturbance days

							Disturbance area (km^2)		Total number of harbour porpoise disturbance days	
id	Country	Estimated number of turbines	density in spring (ind/km^2)	density in summer (ind/km^2)	density in autumn (ind/km^2)	Sound standard (SELss at 750m, in dB re 1 µPa^{2}s)	140 dB standard WITH sound standard	143 dB standard WITH sound standard	140 dB standard WITH sound standard	143 dB standard WITH sound standard
1	BE	44	0.628	0.607	0.386	160	224	128	6204	3520
2	BE	29	0.628	0.607	0.386	160	166	98	3016	1798
3	BE	31	0.628	0.607	0.386	160	232	120	3810	1966
4	BE	31	0.628	0.607	0.386	160	324	194	6107	3658
5	BE	24	0.628	0.607	0.386	160	291	154	4326	2284
6	BE	150	0.628	0.607	0.386	160	204	123	17376	10462
7	BE	70	0.628	0.607	0.386	160	240	134	10510	5844
8	BE	58	0.628	0.607	0.386	160	240	134	8583	4767
9[9]	BE	47	0.628	0.607	0.386	160	332	181	-	-
10	DK	50	0.286	0.277	0.176	-	1651	1352	23060	18918
11	DK	43	0.286	0.277	0.176	-	3036	2396	37324	29455
12	DK	80	0.286	0.277	0.176	-	3259	2477	50729	38534
13	DE	30	0.812	0.785	0.500	160	216	140	5100	3300
14	DE	12	0.812	0.785	0.500	160	373	204	3636	1992
15[10]	DE	19	0.286	0.277	0.176	160	-	-	-	-
16	DE	72	0.286	0.277	0.176	160	234	144	4670	2872
17	DE	55	0.812	0.785	0.500	160	432	231	18645	9955
18	DE	42	0.812	0.785	0.500	160	433	232	14280	7644
19	DE	55	0.812	0.785	0.500	160	433	232	19144	10232
20	DE	67	0.812	0.785	0.500	160	483	265	18406	10111
21	DE	66	0.812	0.785	0.500	160	339	191	17943	10115
22	DE	33	0.812	0.785	0.500	160	341	195	8889	5074
23	DE	71	0.812	0.785	0.500	160	489	267	27524	15050
24	DE	16	0.812	0.785	0.500	160	487	267	6294	3458
25	DE	56	0.812	0.785	0.500	160	224	128	17472	9464

[9] The construction of the Fairy Bank 3, N2000 (BE) farm has been postponed until after 2030.
[10] The construction of the NOR 0-2 Nordergründe (DE) farm was not included due to the shallow water depth (< 10 m).

26	DE	31	0.812	0.785	0.500	160	487	267	11704	6434
27	DE	2	0.812	0.785	0.500	160	488	266	766	418
28	DE	33	0.286	0.277	0.176	160	265	158	2457	1468
29	DE	11	0.286	0.277	0.176	160	421	227	1287	693
30	DE	13	0.286	0.277	0.176	160	429	230	1599	858
31	DE	24	0.812	0.785	0.500	160	384	208	7488	4056
32	DE	24	0.812	0.785	0.500	160	384	208	6897	3735
33	DE	24	0.812	0.785	0.500	160	385	208	7402	3996
34	DE	90	0.812	0.785	0.500	160	492	268	28160	15328
35	DE	19	0.812	0.785	0.500	160	449	243	6688	3629
36	DE	29	0.812	0.785	0.500	160	449	244	10208	5568
37	DE	90	0.812	0.785	0.500	160	491	268	35070	19140
38	DE	63	0.812	0.785	0.500	160	446	242	22470	12215
39	DE	25	0.812	0.785	0.500	160	449	243	8800	4775
40	DE	23	0.812	0.785	0.500	160	495	272	9246	5083
41[11]	DE	45	0.812	0.785	0.500	160	715	363	-	-
42	NL	94	0.628	0.607	0.386	163	285	191	16538	11088
43	NL	79	0.628	0.607	0.386	163	486	289	17373	10333
44	NL	94	0.721	0.698	0.444	165	511	338	27448	18142
45	NL	94	0.721	0.698	0.444	165	482	323	32172	21542
46	NL	6	0.721	0.698	0.444	165	723	454	1515	951
47	NL	95	0.721	0.698	0.444	165	559	379	29422	19952
48	NL	76	0.721	0.698	0.444	165	718	443	36836	22720
49	NL	6	0.721	0.698	0.444	165	689	427	1491	924
50	NL	6	0.721	0.698	0.444	165	689	427	1491	924
51	NL	76	0.721	0.698	0.444	165	734	455	34820	21616
52	NL	6	0.812	0.785	0.500	165	1180	692	2874	1686
53	NL	76	0.812	0.785	0.500	167	1741	1029	106759	63116
54	NL	18	0.721	0.698	0.444	167	1084	692	6813	4347
55	NL	100	0.721	0.698	0.444	165	681	429	35329	22231
56	NL	18	0.721	0.698	0.444	165	808	506	5076	3177
57	NL	100	0.721	0.698	0.444	165	681	429	39109	24611
58	NL	18	0.721	0.698	0.444	165	813	494	5274	3204
59	NL	100	0.721	0.698	0.444	165	766	466	54333	33039
60	NL	100	0.721	0.698	0.444	165	766	466	48846	29693
61	GB	67	0.918	0.888	0.565	-	2852	2282	147583	118054
62	GB	100	0.628	0.607	0.386	-	5700	4760	276700	231040
63	GB	5	0.619	0.599	0.381	-	27024	17993	63262	42121
64	GB	174	0.918	0.888	0.565	-	12552	10180	1703322	1381438
65	GB	102	0.721	0.698	0.444	-	12170	10187	742810	621802

[11] The construction of the N-6.6 (DE) farm has been postponed until after 2030.

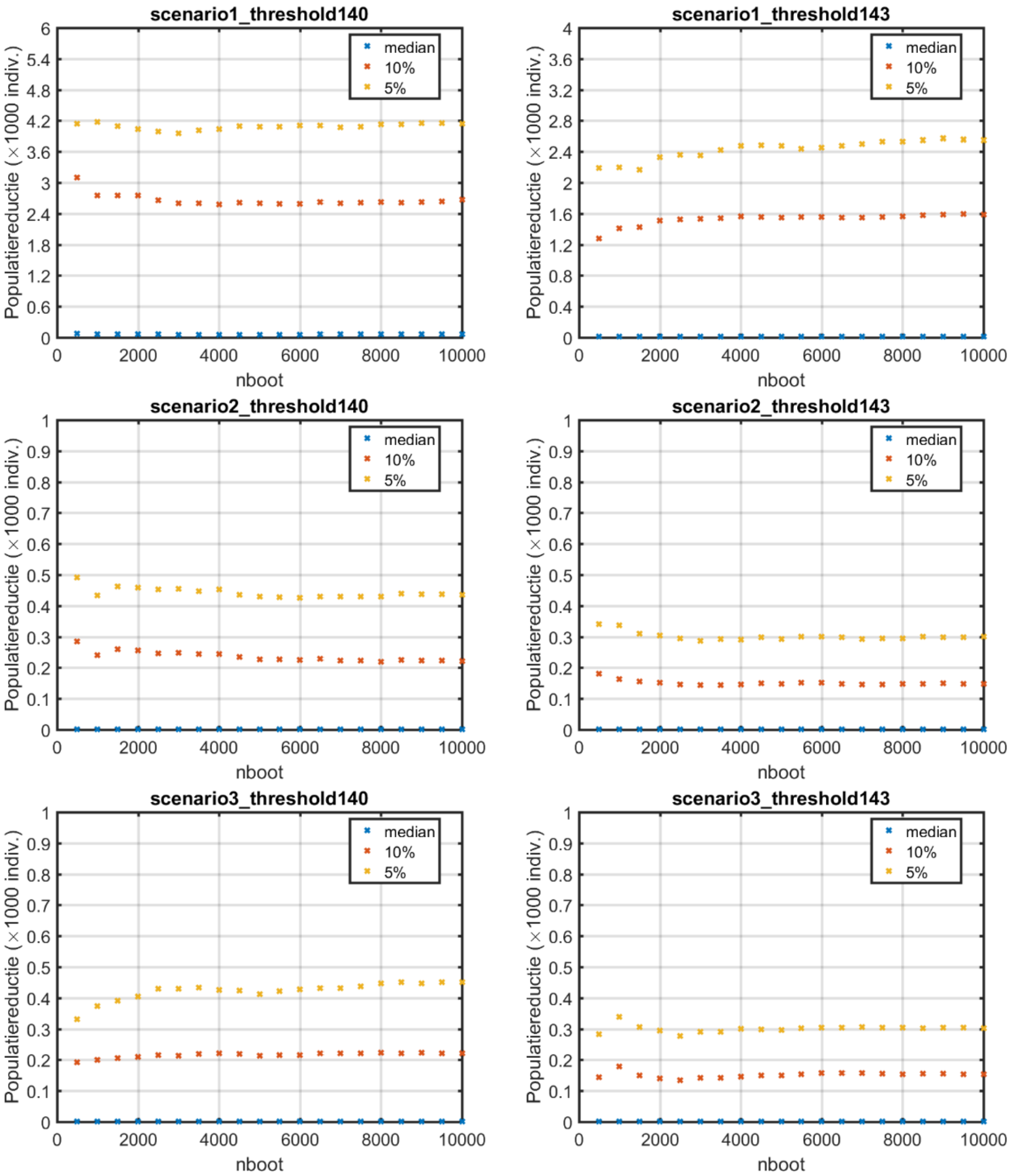
66	GB	131	0.619	0.599	0.381	-	17018	12072	1236694	877255
67	GB	6	0.619	0.599	0.381	-	11783	8161	43764	30312
68	GB	110	0.619	0.599	0.381	-	36549	22336	1978104	1208860
69	GB	84	0.619	0.599	0.381	-	27925	18327	1406867	923312
70	GB	56	0.619	0.599	0.381	-	14488	10249	501048	354444
71	GB	173	0.918	0.888	0.565	-	12838	10263	1795089	1435101
72	GB	78	0.619	0.599	0.381	-	19996	13566	884364	599970
73	GB	34	0.628	0.607	0.386	-	5685	4704	121380	100436
74	GB	105	0.619	0.599	0.381	-	30299	21209	1942005	1359360
75	GB	75	0.619	0.599	0.381	-	15361	10936	582939	415037
76	GB	80	0.721	0.698	0.444	-	11370	9384	641954	529832
77	GB	80	0.721	0.698	0.444	-	12026	10032	678168	565704
78	GB	300	0.918	0.888	0.565	-	12694	10224	1233541	993572
79	GB	150	0.721	0.698	0.444	-	11056	8950	215996	174856
80	GB	180	0.721	0.698	0.444	-	10884	8735	1027982	825027
81	GB	180	0.721	0.698	0.444	-	7746	6095	596487	469310

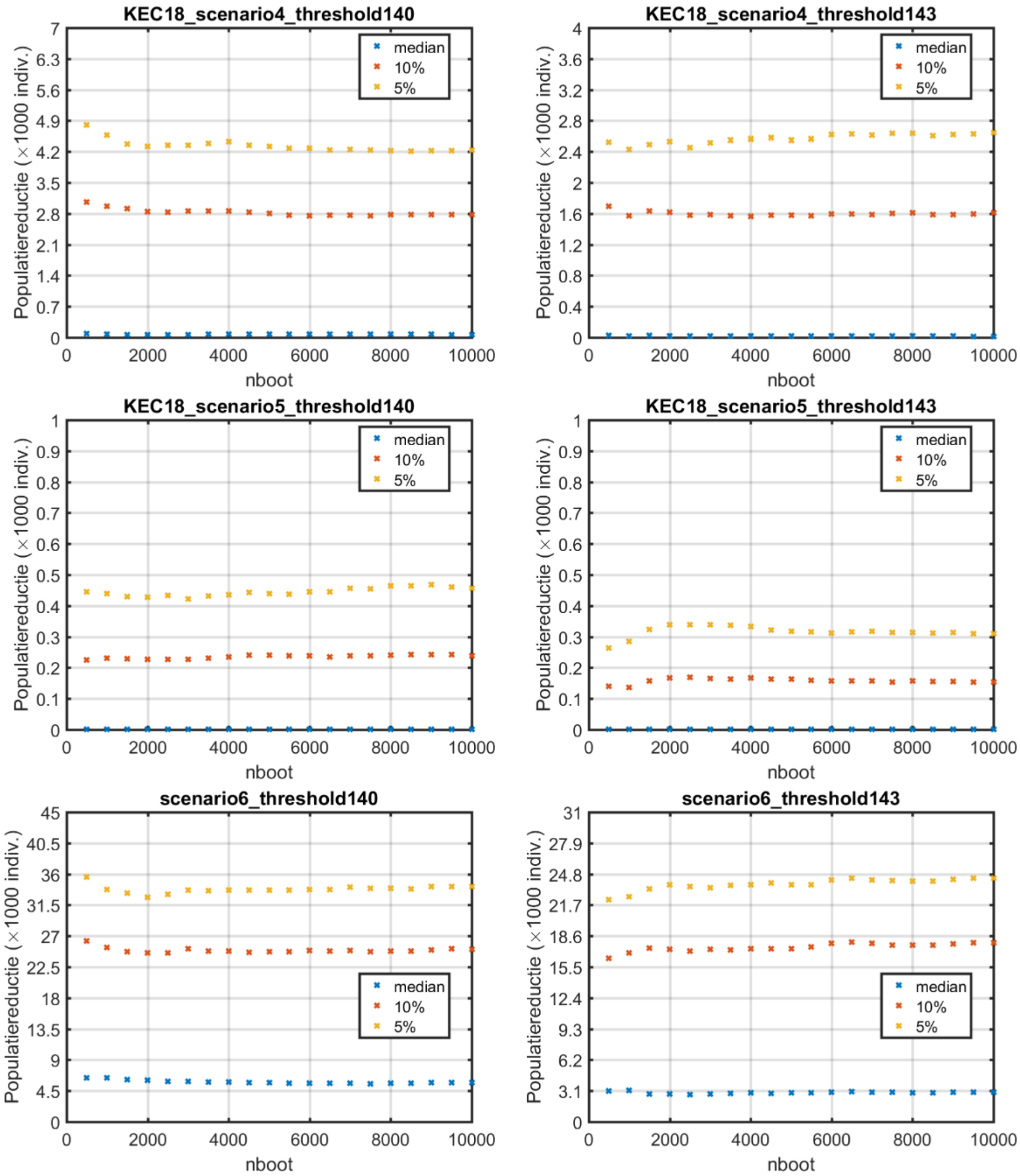
Dutch wind farms after 2023

id	Name	Estimated number of turbines	Disturbance area (km²)				Total number of harbour porpoise disturbance days			
			140 dB standard WITHOUT mitigation	143 dB standard WITHOUT mitigation	140 dB standard WITH mitigation	143 dB standard WITH mitigation	140 dB standard WITHOUT mitigation	143 dB standard WITHOUT mitigation	140 dB standard WITH mitigation	143 dB standard WITH mitigation
48	Hollandse Kust (West)	76	4960	3970	718	443	254520	203722	36836	22720
51	Hollandse Kust (West)	76	5530	4337	734	455	262450	205830	34820	21616
53	Ten Noorden van de Waddeneilanden	76	13724	10457	1741	1029	841379	641086	106759	63116
55	IJmuiden Ver	100	6310	4896	681	429	327680	254238	35329	22231
57	IJmuiden Ver	100	6310	4896	681	429	362640	281358	39109	24611
59	IJmuiden Ver	100	6086	4794	766	466	431660	339990	54333	33039
60	IJmuiden Ver	100	6086	4794	766	466	387970	305605	48846	29693
Total disturbance days due to piling of turbine foundations							**2868299**	**2231829**	**356032**	**217026**
49	Hollandse Kust West Beta Platform	6	2378	1751	689	427	12687	10068	1911	1239
50	Hollandse Kust West Gamma Platform	6	2378	1751	689	427	12687	10068	1911	1239
52	North of Wadden Alpha Platform	6	4791	3380	1180	692	31515	24171	4533	2793
54	IJmuiden Ver Alpha Platform	18	2688	1994	1084	692	40743	32121	6354	4005
56	IJmuiden Ver Beta Platform	18	2688	1994	808	506	40743	32121	4725	2925
58	IJmuiden Ver Gamma Platform	18	2834	2075	813	494	46647	36441	5418	3303
Total disturbance days due to piling of platforms							**185,022**	**144,990**	**24,852**	**15,504**
disturbance days due to platforms/turbine foundations							**6%**	**6%**	**7%**	**7%**

Annex 6: Results of Interim PCoD (v5)

Calculated percentiles 5%, 10% and 50% (= median) for the additional population reduction due to the work in the years 2016 to 2030 determined as an average of the calculated differences between the undisturbed and disturbed populations in the years 2031 through to 2040 as a function of the number of model runs (nboot) per scenario. The ultimate population reduction was calculated as an average and variation (standard deviation) of the results for 4000 to 10000 model runs (in steps of 500 runs).




KEC18_scenario4_threshold140
KEC18_scenario4_threshold143
KEC18_scenario5_threshold140
KEC18_scenario5_threshold143
scenario6_threshold140
scenario6_threshold143
Populatiereductie (×1000 indiv.)
nboot
median
10%
5%

Annex 7: Options for standards for piling sound for wind energy areas after 2023

Annex Table 7-1 Standards for piling sound (SELss in dB re 1 µPa²s) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in spring.

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	**1,275**	**638**	**319**
48	Hollandse Kust (west)	2024	760	76	183	175	168	162
51	Hollandse Kust (west)	2025	760	76	182	175	168	162
53	Ten Noorden van de Waddeneilanden	2026	760	76	173	168	164	160
55	IJmuiden Ver	2027	1000	100	181	174	168	163
57	IJmuiden Ver	2028	1000	100	181	174	168	163
59	IJmuiden Ver	2029	1000	100	181	174	168	162
60	IJmuiden Ver	2030	1000	100	181	174	168	162

*Annex Table 7-2 Standards for piling sound (SELss in dB re 1 µPa*2s*) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in summer.*

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	**1,275**	**638**	**319**
48	Hollandse Kust (west)	2024	760	76	183	175	169	163
51	Hollandse Kust (west)	2025	760	76	182	175	168	162
53	Ten Noorden van de Waddeneilanden	2026	760	76	173	168	164	160
55	IJmuiden Ver	2027	1000	100	181	175	169	163
57	IJmuiden Ver	2028	1000	100	181	175	169	163
59	IJmuiden Ver	2029	1000	100	181	174	168	162
60	IJmuiden Ver	2030	1000	100	181	174	168	162

Annex Table 7-3 Standards for piling sound (SELss in dB re 1 µPa2s) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in autumn.

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	**1,275**	**638**	**319**
48	Hollandse Kust (west)	2024	760	76	189	181	173	165
51	Hollandse Kust (west)	2025	760	76	188	180	172	165
53	Ten Noorden van de Waddeneilanden	2026	760	76	177	171	167	162
55	IJmuiden Ver	2027	1000	100	187	179	172	166
57	IJmuiden Ver	2028	1000	100	187	179	172	166
59	IJmuiden Ver	2029	1000	100	187	179	171	165
60	IJmuiden Ver	2030	1000	100	187	179	171	165

Annex Table 7-4 Standards for piling sound (SELss in dB re 1 μPa2s) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in spring. For 15 MW turbines.

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	1,275	638	319
48	Hollandse Kust (west)	2024	760	51	188	180	172	165
51	Hollandse Kust (west)	2025	760	51	187	179	172	165
53	Ten Noorden van de Waddeneilanden	2026	760	51	176	171	166	162
55	IJmuiden Ver	2027	1000	67	186	178	172	165
57	IJmuiden Ver	2028	1000	67	186	178	172	165
59	IJmuiden Ver	2029	1000	67	185	178	171	164
60	IJmuiden Ver	2030	1000	67	185	178	171	164

Annex Table 7-5 Standards for piling sound (SELss in dB re 1 μPa2s) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in summer. For 15 MW turbines.

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	1,275	638	319
48	Hollandse Kust (west)	2024	760	51	189	180	172	165
51	Hollandse Kust (west)	2025	760	51	187	179	172	165
53	Ten Noorden van de Waddeneilanden	2026	760	51	176	171	166	162
55	IJmuiden Ver	2027	1000	67	186	179	172	165
57	IJmuiden Ver	2028	1000	67	186	179	172	165
59	IJmuiden Ver	2029	1000	67	186	178	171	165
60	IJmuiden Ver	2030	1000	67	186	178	171	165

*Annex Table 7-6 Standards for piling sound (SELss in dB re 1 μ*Pa2s*) for wind energy areas after 2023 in line with 2018 KEC, for pile-driving in autumn. For 15 MW turbines.*

id	Name	year	Capacity (MW)	Estimated number of turbines	sound standard [dB] depending on maximum population reduction in 2030 (individuals)			
					2,550	1,275	638	319
48	Hollandse Kust (west)	2024	760	51	190	186	177	169
51	Hollandse Kust (west)	2025	760	51	190	184	176	168
53	Ten Noorden van de Waddeneilanden	2026	760	51	181	174	169	164
55	IJmuiden Ver	2027	1000	67	190	184	176	168
57	IJmuiden Ver	2028	1000	67	190	184	176	168
59	IJmuiden Ver	2029	1000	67	190	183	175	168
60	IJmuiden Ver	2030	1000	67	190	183	175	168

Annex 8: Consequences of the application of uniform sound standard after 2023

The construction of the wind farms in the Energy Agreement in line with the sound standards previously established will result in a maximum number of 146,572 harbour porpoise disturbance days through to 2023 for pile-driving in the spring (worst case), see Annex Table 8-1.

Annex Table 8-1 Calculation of harbour porpoise disturbance days per year for the planned construction of wind farms in line with the Energy Agreement

id	Name	year	Capacity (MW)	Estimated number of turbines	standard [dB]	Harbour porpoise disturbance days
42	Tender 2015 - Borssele I/II	2020	752	94	163	16,824
43	Tender 2016 - Borssele III/IV	2020	732	79	163	24,160
44	Tender 2017 - Hollandse Kust (south) I/II	2021	752	94	165	34,633
45	Tender 2018 – Hollandse Kust (south) III/IV	2021	752	94	165	32,667
47	Tender 2019 - Hollandse Kust (north) V	2023	760	95	165	38,289
					Total	**146,572**

For the construction of the wind farms from 2024 onwards by pile-driving turbine foundations and transformer platforms using a uniform sound standard of SELss 168 dB 1 re $\mu Pa^2 s$ (750), 570,858 and 70,801 (total: 641,659) harbour porpoise disturbance days respectively, see Annex Table 8-2.

Annex Table 8-2 As Annex Table 8-1 for wind farms from 2024 onwards with 10 MW wind turbines, including transformer platforms

id	Name	year	Capacity (MW)	Number of piles	standard [dB]	Harbour porpoise disturbance days
48	Hollandse Kust (west)	2024	760	76	168	58,193
51	Hollandse Kust (west)	2025	760	76	168	59,892
53	Ten Noorden van de Waddeneilanden	2026	760	76	168	126,016
55	IJmuiden Ver	2027	1000	100	168	77,291
57	IJmuiden Ver	2028	1000	100	168	77,291
59	IJmuiden Ver	2029	1000	100	168	86,087
60	IJmuiden Ver	2030	1000	100	168	86,087
	Total disturbance days due to piling of turbine foundations					**570,858**
46	Hollandse Kust West Alpha Platform	2023		6	168	4,681
49	Hollandse Kust West Beta Platform	2024		6	168	4,451
50	Hollandse Kust West Gamma Platform	2024		6	168	4,451
52	North of Wadden Alpha Platform	2025		6	168	9,237
54	IJV Alpha Platform	2026		18	168	16,002
56	IJV Beta Platform	2027		18	168	16,002
58	IJV Gamma Platform	2028		18	168	15,976
	Total disturbance days due to piling of platforms					**70,801**
	Total disturbance days					**641,659**

The harbour porpoise disturbance days resulting from the execution of the individual geophysical surveys are listed in Annex Table 8-3.

Annex Table 8-3 Calculated harbour porpoise disturbance days as a result of geophysical surveys in the wind energy areas and along the planned cable routes

no	Name	Number of days	Harbour porpoise disturbance days
82	GS Hollandse Kust South I & II	10	590
83	GS Hollandse Kust South III & IV	10	530
84	GS Hollandse Kust North I & II	11	649
85	GS Hollandse Kust West	12	690
86	GS Hollandse Kust West	12	708
87	GS Ten Noorden van de Waddeneilanden	12	636
88	GS IJmuiden Ver	16	944
89	GS IJmuiden Ver	16	944
90	GS IJmuiden Ver	16	848
91	GS IJmuiden Ver	16	384
92	GS Borssele I & II	11	264
93	GS Borssele III & IV	12	612
94	GS Hollandse Kust South I & II	10	590
95	GS Hollandse Kust South III & IV	10	680
96	GS Hollandse Kust North I & II	11	649
97	GS Hollandse Kust West	12	568
98	GS Hollandse Kust West	12	708
99	GS Ten Noorden van de Waddeneilanden	12	816
100	GS IJmuiden Ver	16	944
101	GS IJmuiden Ver	16	944
102	GS IJmuiden Ver	16	1,088
103	GS IJmuiden Ver	16	1,088
104	GS cable route Hollandse Kust West Beta	9	243
105	GS cable route Ten Noorden van de Waddeneilanden Alpha	14	378
106	GS cable route IJmuiden Ver Alpha, Beta and Gamma	60	1,311
107	GS cable route Hollandse Kust West Beta	9	243
108	GS cable route Ten Noorden van de Waddeneilanden Alpha	14	378
109	GS cable route IJmuiden Ver Alpha, Beta and Gamma	60	1,311
		Total geophysical surveys	**19,738**

The total number of harbour porpoise disturbance days due to pile-driving (with set sound standards for round-two wind farms and a uniform sound standard of 168 dB for wind farms after 2023, for the current estimate of numbers of piles and for pile-driving in the spring) plus geophysical surveys is **807,969**, see Annex Table 8-4. It follows from the approximation formula that this results in a 5% probability of a population reduction of **865** individuals.

Annex Table 8-4 Harbour porpoise disturbance days due to the construction of wind farms in the period 2016 - 2030, with variable sound standards for round-two wind farms and a uniform sound standard for wind farms after 2023.

Total due to piling of turbine foundations in round-two wind farms in spring	146,572
Total due to piling foundations for turbines and transformer platforms after 2023 (168 dB standard)	641,659
Total disturbance days due to geophysical surveys	19,738

TOTAL	**807,969**