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Review of underwater noise prognosis for Vesterhav N and S

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Summary

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1 Introduction

In relation to the construction of Vesterhav Nord and Syd offshore wind farms, Energistyrelsen (Danish Energy Agency) has received two prognosis draft reports of underwater noise during pile driving of the wind turbine foundations: Vesterhav Nord [1] and Syd [2], respectively. The two reports are very similar, mainly differing in foundation positions. The numerical results presented in tables 4, 5, and 6 are the same for both reports. On that background, the comments of this review referring to the "prognosis" in singular in fact apply for both reports.

Lloyd's Register Consulting – Energy A/S (Hereafter LR) has been requested by Energistyrelsen to perform a review of the prognosis reports (hereafter Prognoses, and Prognosis Reports) in terms of compliance with Danish guideline for underwater noise (hereafter DK Guideline) [3]. The DK Guideline states a noise limit of 190 dB, expressed as cumulative Sound Exposure Level SELc for a fleeing animal.

In addition to the prognoses, an accompanying report [4] was received, which describes the technical background of the prognosis model. However, the content of the latter is practically the same as found in the prognosis reports and will not be addressed further.

Also, a separate report was provided, describing in-situ sparker-based sound propagation measurements [5].

A note: The DK Guideline uses the term "prognosis". Equally common (and synonymous) terms are "prediction" and "forecast".

2 General comments to Prognosis

The prognosis was prepared by ITAP (Institute for Technical and Applied Physics GmbH) on behalf of Vattenfall. ITAP applies a semi-empirical approach, relying on a simple sound transmission loss proposed in the DK Guideline.

The applied modelling scheme is presented in the Prognosis Report. In general, such a semi-empirical approach is allowed by the DK Guideline, as long as site-specific properties are correctly represented. For the Prognosis, particularly with regards to the important sound transmission properties a worst-case rather than detailed approach is applied.

Assessment of the prognosis results is done against several requirements beyond the DK Guideline's scope. A specific conclusion on compliance of the DK Guideline criteria is lacking.

It was beyond the scope of this review for LR to perform an alternative noise prognosis. However, a spot-check of the unweighted single-strike SEL at 750 m of 180 dB (assuming Table 4 corresponds to hammer energy 3000 kJ) seems reasonable from LR's experience.

3 Specific comments to Prognosis

3.1 Comments relating to DK Guideline

The DK Guideline assumes the noise model to consist of a noise source part and a noise propagation part, respectively. Regardless of the type of propagation model, the noise propagation shall be expressed in the format $X \cdot Log_{10}(r) + A \cdot r$ with r being the distance from the source. The constants X and A shall be derived using curve fitting.

The following issues are listed in order of appearance according to the text location of the requirement in the DK Guideline.

3.1.1 The noise source characterisation shall be determined individually for each pile position

LR's comment: This is indeed done for each pile. The prognosis starts by assessing the single-strike SEL and Peak Level at 750 m, since this distance is the basis of ITAP's extensive, empirical database. This is well described, including assessments of expected level of uncertainty.

While not a requirement, we recommend showing the three considered foundation positions in the same overview plot, e.g. the site overview of Figure 1.

3.1.2 Methodology for sound propagation

LR's comment: The prognosis method applies a broadband transmission loss (TL) expression stated in the DK Guideline as an example (Section "Calculation example" at the end of the DK Guideline). Note that this expression is not frequency dependent. While this may seem a little strange, since the prognosis report correctly emphasises that underwater noise propagation is in fact frequency dependent, it may be argued that the DK Guideline does not strictly require frequency dependent calculations, see comments in next section (Section 3.1.3).

The prognosis report in Sect. 6.1 has a good discussion of the applied broadband TL expression compared to previous *in-situ* sparker based TL measurements and literature. Some comments:

- The literature source "Betke & Matuschek, 2017" for sparker measurements is missing from the literature list.
- The "Thiele & Schellstede (1980)" semi-empirical, frequency dependent TL formula refers to a German FWG-report, which was declassified just recently. The formula (Equation no. 11) is not directly found in that FWG report. Although this formula is not used for the actual prognosis, it would seem relevant with a statement linking the formula with the FWG report.
- The TL measurement report [5] describes that a typical piling noise signal typically has maximum energy content between 100-300 Hz, while the applied sparker signal has maximum at 1k-2kHz. It is argued that the water is locally sufficiently deep, causing the shallow-water cut-off phenomenon to not significantly affect neither of the two signal types. It is LR's opinion that this is probably correct for the broadband considerations relevant to the DK Guideline criteria. However, it is noted that when applying frequency weightings such as for several of the other criteria used in the Prognosis Reports, this lack of frequency dependent assessment of the propagation might be an oversimplification.
- It is noted that the TL measurement report [5] concludes that "*…result of this report is, that sparkers for geophysical investigations are not necessarily a suitable sound source for transmission loss measurements.*" On that background, these measurements should only be applied for early-stage, preliminary studies.

3.1.3 The sound propagation characterisation shall include estimation of the spectrum of transmitted noise

LR's comment: The Prognosis Report indeed shows frequency spectra of the transmitted noise as a function of distance (Figure 10, top).

It is noted that the DK Guideline does not directly state that propagation modelling be carried out in a frequency dependent manner. However, it seems reasonable to interpret this as being the implicit intention of the DK Guidelines, as the following requirements are indeed stated:

- The spectrum of the unweighted noise source shall be presented

- The spectrum of the transmitted noise shall be included in the sound propagation characterisation
- Single-strike as well as cumulative SEL shall be presented in 1/3-octave band spectra at 750 m from the source, as well as back-propagated to 1 m distance
- Insertion loss of the proposed noise mitigation method shall be presented in 1/3-octave band spectra

3.1.4 The bathymetry at the site shall be taken into account for the sound propagation modelling

LR's comment: The prognosis report correctly shows the bathymetry at and around the site in Figure 1. Furthermore, the rather small variation in water depth (within 6 m) inside the site is stated in the text.

On page 14, the text says "*The transmission loss will be considered for each direction. Site specific changes in bathymetry, especially towards the shore, will be considered by the frequency dependent impact of water depth as described below*". This seems contradictory to the statement in Section 6.4.6 that "equation no. 10" is used, i.e. the frequency independent propagation formula included as example in the DK Guideline. In the following it is assumed that the propagation has indeed been implemented as "equation no. 10".

In the model procedure, the water depth is only accounted for as a correction to the source level. No correction is done to the sound propagation. Such a correction would be frequency dependent, which conflicts with the applied broadband expression for sound propagation.

It is noted that bathymetry matters from an acoustical view-point, as:

- Upslope/uphill propagation generally corresponds to increased transmission loss
- Downslope/downhill propagation generally corresponds to less transmission loss

The shallow-water cut-off effect [4] generally attenuates low-frequency energy content strongly. This happens below a cut-off frequency, which depends on seabed material and water depth. In Sect. 6.4.5 the cut-off frequency is assessed as 32-41 Hz depending on foundation position.

Most likely, since the bathymetry in the area appears to be relatively flat, the influence is probably small. However, radials pointing towards land will have upslope conditions whereas radials towards open sea will, from looking at the bathymetry map, have different conditions in e.g. Northern direction vs. Western. We would recommend including a plot of water depth vs. distance for representative radials, e.g. for the DK Guideline's suggested minimum 18 radials. This will probably support the decision of not accounting for the bathymetry in the sound propagation.

It is noted that although the DK Guideline requires a minimum of 18 radials (or transects) to be plotted, it does not directly specify that each radial must have separate bathymetry properties. As the applied TL method is independent of variations in bathymetry, the noise maps such as Figure 11 predict symmetric sound fields in all directions away from the coastline. This is a simplification of the actual conditions, which would show some variation over the radials. The applied approach should be seen as conservative.

3.1.5 Realistic water sound speed profiles shall be assumed

LR's comments: Section 7.1. Existing conditions has a good discussion of water sound speed (/velocity) profiles. It is assessed that a well-mixed water column applies. In LR's experience, this is a reasonable, conservative assumption. Water sound speed is assumed to be constant 1480 m/s across the water column.

3.1.6 The acoustic properties of the topmost seabed soils shall be accounted for in the sound propagation

LR's comments: The applied propagation model has range dependence but does not account for sea bed properties. This is in conflict with the DK Guideline's requirement of taking into account the acoustic properties of the topmost sea bed soils. On the other hand, the prognosis report demonstrates that the applied propagation model is in fair agreement with both site specific propagation measurements and a more general semi-empirical North Sea propagation formula from literature. Hence, the non-stated acoustic properties of the seabed may be considered as indirectly accounted for in the model.

Figure 2 includes a geological cross section. The source of this graphic should be included.

3.1.7 Report shall include tables of acoustic properties used for sea bed soils

LR's comments: The prognosis report includes an overall qualitative introduction to the area geological composition. However, the DK Guideline requires tables of acoustic sea bed properties. Usually, these are minimum density, compressional wave speed, and compressional wave attenuation. This is not included, which is in principle a deviation from the DK Guideline requirements. However, it may be argued that such tables would be informative only, as the data is not directly used in the applied semi-empirical model.

3.1.8 The installation characterisation shall include expected variation of hammer energy

LR's comments: In Table 1 the prognosis report presents the assumed hammering protocol. Being a smaller issue, the piling protocol (/piling sequence) is described as having soft-start and ramp-up durations of 15 and 28 minutes respectively, whereas the actual numbers seem closer to 16 and 25 minutes. This should be clarified.

It is noted that the procedure of the DK Guideline assumes the animal to keep fleeing at a constant velocity. In the hammer protocol of the prognosis, this includes the (approximately) 15 minutes period of no piling. This is in line with the current version of the DK Guideline, but it may a topic for a future revision to clarify the animal behaviour during long periods without piling activity.

3.1.9 Report shall include "noise maps" showing special variation of single-strike SEL. At least 18 radials are recommended

LR's comments: Such maps are indeed included. However, since bathymetry and geoacoustic properties are assumed to be identical for all radials, the maps essentially show no further information than a single noise level vs. distance plot (such as in Figure 10).

3.1.10 Report shall describe assumed efficiency of suggested noise mitigation on spectral basis

LR's comments: This is indeed addressed and discussed in good detail. The assumed level noise mitigation used in the results table, Table 9 seems reasonable.

3.1.11 Prediction results at 750 m from sound source

LR's comments: The DK Guideline requires presentation of single-strike SEL (both broadband and as 1/3-oct spectra) at range 750 m from the sound source, for both un-mitigated and mitigated cases. The broadband values are included in Table 4 of the prognosis report, though it is not stated whether Table

4 corresponds to full nominal hammer energy 3000 kJ. This should be clarified. The corresponding 1/3-octave spectra are shown as a colour-map in Figure 10, but it is hard for the reader to assess the absolute spectral levels from the colours. Since the prognosis propagation model is stated to be frequency independent, it is suggested to replace the topmost plot of Figure 10 by a 1/3-octave band spectrum corresponding only to 750 m distance.

Broadband and 1/3-octave spectra of the noise in the 10 dB-mitigation case of Table 9 should be included in the report.

3.2 Calculation and evaluation of cumulative Sound Exposure Level

LR's comments: The prognosis report presents predicted cumulative SEL according to numerous criteria and frequency weightings beyond that of the DK Guideline. It should be kept in mind that the DK Guideline's time basis differs from that of e.g. the National Marine Fisheries Service (NMFS) [7]:

- DK Guideline uses the term "SELc" corresponding to cumulative SEL over the duration of the piling
- NMFS uses the term "SELcum" for cumulative SEL over 24 hours

We suggest distinguishing between SELc and SELcum in the Prognosis Report. In the current review, the Prognosis Report's current use of "SELcum" is used.

DK Guideline criteria for SELc: Table 5 of the prognosis report includes a row "Harbour porpoise" with animal fleeing speed 1.5 m/s. The predicted SELcum is 200 dB at 750 m. Probably, this is to be interpreted as the main results of the prediction in relation to the DK Guideline criteria of SELcum. This is not at all clear to the reader. It is essential that this numerical result as well as a comparison to the criteria be highlighted, as a minimum in a conclusion section.

The appendix of the prognosis report includes a number of noise maps corresponding to SELcum in case of fleeing animals. However, since the dB levels decrease with distance these plots seem to be fixed-position receptor SEL rather than moving receptor. For an animal moving continuously away from the source, an increasing SELcum over distance would be expected. It should be clarified what these plots actually show. It should also be double-checked if all legend information is correct (as an example, the plot on page 44 says "HP, Phocid Seals" ("HP" is maybe intended to mean "HF") but as "unweighted SELcum", which is contradictory).

Other criteria for SELcum: Although this review focusses on the DK Guideline, a few comments are made. In particular, it seems odd to combine a broadband, frequency independent propagation with strongly frequency dependent weighting functions. According to Table 9, some of the assessed distances to threshold are in the order of several tens of km. It seems incorrect to assume that the spectral shape remains unchanged over such large propagation distances.

4 General comment on prediction uncertainty

LR's comments: The output of any numerical prediction model has an inherent degree of uncertainty, depending on factors such as model assumptions, precision of input data, etc. The prognosis report has good discussions on the sound source representation, stating an uncertainty of +/- 2 dB when assessed at 750 m from the source. Although not required by the DK Guideline, it is LR's opinion that similar discussion would be relevant for prediction metrics at larger distances, e.g. up to 2 km. This is particularly motivated by the fact that the applied sound propagation model is not site specific. It is noted that the Thiele & Schellstede source includes quantitative information on long-distance uncertainties.

5 Conclusion

The following applies to both Prognosis Reports [1] and [2]:

The Prognosis has good estimates of source level and proposed noise mitigation. As for the approach to sound propagation, what can be regarded as a conservative approach is applied, whereas the DK Guideline requires a high level of details. However, it seems likely that the Prognosis results are indeed representative for Vesterhav Nord and Syd, with a certain conservatism. It is recommended to include further discussions on expected accuracy in the Prognosis Report, particularly aimed at the cumulative SEL criteria of the DK Guideline.

The most significant issue compared to the DK Guideline is missing, specific addressing and discussion of the DK Guideline's criteria of cumulative SEL ≤ 190 dB. Only an overall statement is made in the summary at the beginning of the reports.

Although 1/3-octave band spectra are presented throughout the report, the applied sound propagation method is not frequency independent. This appears to be a deviation from the intentions of the DK Guideline.

There is a number of distracting typos/misprints in the prognosis report. Thorough proof-reading is recommended.

5.1 Issues related to current Guideline version

Some issues are found that mainly derive from lack of clarity of the current version of the DK Guideline. As an example, the DK Guideline requires sound propagation to be addressed along a minimum of 18 azimuthal radials. This is indeed practical in a modelling context, whereas for on-site sound propagation measurements is less realistic to perform specific measurements for that many transects. For future revisions of the DK Guideline it would make sense to more clearly distinguish between requirements from a pure numerical approach versus a one including semi-empirical model steps.

It is also suggested as a topic for future revision work to clarify animal fleeing behaviour during intervals without hammer activity.

5.2 Overall conclusion

Generally, it is LR's opinion that the two Prognosis Reports show acceptable approaches and realistic results for an early-stage study. There are however a number of less critical issues concerning the report that should be addressed.

It is suggested to request a more detailed study at a later stage of the project. At that point, care should be taken to identify transmission loss in the directions that are expected to be the most critical in terms of underwater noise. In line with the conclusion of the underlying measurement report [5] for the current prognosis work, a more reliable method than sparker technique should be used for transmission loss determination.

6 References

[1] Remmers, P. Vesterhav Nord Offshore Wind Farm EIA – Technical report – Modelling of underwater noise emissions during construction pile-driving work. Oldenburg: Institute for Technical and Applied Physics GmbH (ITAP); Feb 6th 2020. 60 p. Report No.: DRAFT Version 4

[2] Remmers, P. Vesterhav Syd Offshore Wind Farm EIA – Technical report – Modelling of underwater noise emissions during construction pile-driving work. Oldenburg: Institute for Technical and Applied Physics GmbH (ITAP); Feb 6th 2020. 59 p. Report No.: DRAFT Version 3

[3] Energistyrelsen. Guideline for underwater noise – Installation of impact-driven piles. Energistyrelsen; April 2016.

[4] Remmer, P. Itap underwater noise prognosis - Technical description of the pile driving noise model. Odenburg: Institute for Technical and Applied Physics GmbH (ITAP); Feb. 1st 2018. 22 p. Report No. Version 1.

[5] Betke K, Matuschek R. Measurement of underwater acoustic transmission loss in the Vesterhav Nord and Vesterhav Syd Wind farm areas. Oldenburg: Institut für technische und angewandte Physik GmbH (ITAP); October 12th 2017. 37 p. Report Version 3.

[6] Jensen FB, Kuperman WA, Porter MB, Schmidt H. Computational Ocean Acoustics. 2nd ed. New York: Springer-verlag; 2011.

[7] National Marine Fisheries Service. 2018 Revision to: Technical guidance for assessing the effects on anthropogenic sound on marine mammal hearing (Version 2.0): Underwater thresholds for onset of permanent and temporary threshold shifts.U.S Dept. of Commer., NOAA. Technical Memorandum NMFS-OPR-59