CHAPTER 4

EVALUATING UNDERWATER NOISE REGULATIONS FOR PILING NOISE IN BELGIUM AND THE NETHERLANDS

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ABSTRACT

There is concern about possible effects on the marine ecosystem of high levels of underwater noise generated during pile driving for the construction of offshore wind farms. As a result, various national governments in Europe have identified limits of underwater sound levels, as such imposing in many cases the use of noise mitigation measures. In this paper we compare the regulations with regard to impulsive underwater noise in the Belgian wind farm zone with those in the Dutch wind energy zone of Borssele. These (planned and existing) wind farms are situated at opposite sides of the maritime border between both countries. These regulations are quite different and at times even contradictory and developers could benefit from an alignment of regulatory practices on a regional basis. Measurements of piling noise from constructed wind farms are used to extrapolate the anticipated noise levels of the next two wind farms to be constructed, and these are evaluated in relation to the new regulations on underwater sound. Wind farm developers are already developing strategies for cost-effective piling noise reduction but uncertainty remains with regards to both the level of underwater noise produced during piling as well as with the effectiveness of the noise mitigation measures being applied. Our results indicate that a combination of noise mitigation measures may need to be used to comply with the new regulations.

4.1 INTRODUCTION

At the end of 2015, 11.6 GW of offshore wind capacity was operational in the Southern North Sea and a further 20.3 GW was consented and scheduled to be constructed in the next decade (EWEA, 2016). During 2015, more capacity was installed than ever before and work was carried out on 22 offshore wind farms in Europe (EWEA, 2016). Understanding the environmental impact of offshore wind farms is necessary to support policy and management of this publicly subsidized industry. Environmental impact monitoring of offshore wind farms has been ongoing since 2000 (Danish Energy Agency, 2013), and the effect of piling noise on marine mammals, and in particular the harbour porpoise (*Phocoena phocoena*), is recognized as one of the major environmental drivers for underwater noise regulations as it concerns a species sensitive to sound (Lepper *et al.,* 2008), legally protected nationally and internationally (Dolman et al., 2016) and the effect of piling noise has been demonstrated to extend over a large distance (Brandt et al., 2011; 2012, Haelters et al., 2015). Potential effects of piling noise on marine mammals range from auditory masking, behavioural disturbance, physiological stress, hearing loss (temporary or permanent) up to physical injury or death (Lucke et al., 2009).

In the European Marine Strategy Framework Directive (MSFD; 2008/56/EC) member states should aim to achieve or maintain good environmental status (GES) by 2020 at the latest. For the introduction of energy, including underwater noise, GES requires anthropogenic underwater noise to be at levels that do not adversely affect the marine environment. To implement the MSFD for anthropogenic impulsive sounds, Belgium adopted an interim criterion of a maximum zero to peak noise level (L_{z-p}) of 185 dB re 1 µPa at 750 m from the source (Anonymous, 2012a). In the Netherlands, it has been argued that, lacking certain information on the impact of impulsive sounds on the marine ecosystem, no general criterion could be defined in 2012. Additional studies were since conducted to address these knowledge gaps (Anonymous, 2012b). The Netherlands however agreed that, mitigating measures should be taken at a case by case basis for activities such as piling and seismic investigations, to prevent negative impacts on the marine fauna (Anonymous, 2012b). This difference in approach in neighbouring countries is not surprising, as so far all European member states which have defined GES for underwater noise have used different approaches (Dekeling, 2015).

In practice, underwater noise regulations for individual projects in both Belgium and the Netherlands are to a large extent stipulated in the *environmental permit* (Belgium) and in the *Kavelbesluit* (The Netherlands) (Table 1).

In this chapter, measurements of piling noise (zero to peak sound pressure level Lz-p and unweighted sound exposure level SEL) from constructed wind farms are used to extrapolate the anticipated piling noise levels of the next two Belgian wind farms to be built (Figure 1) and these are evaluated in relation to the Belgian and Dutch regulations in order to determine what level of noise mitigation will be needed.

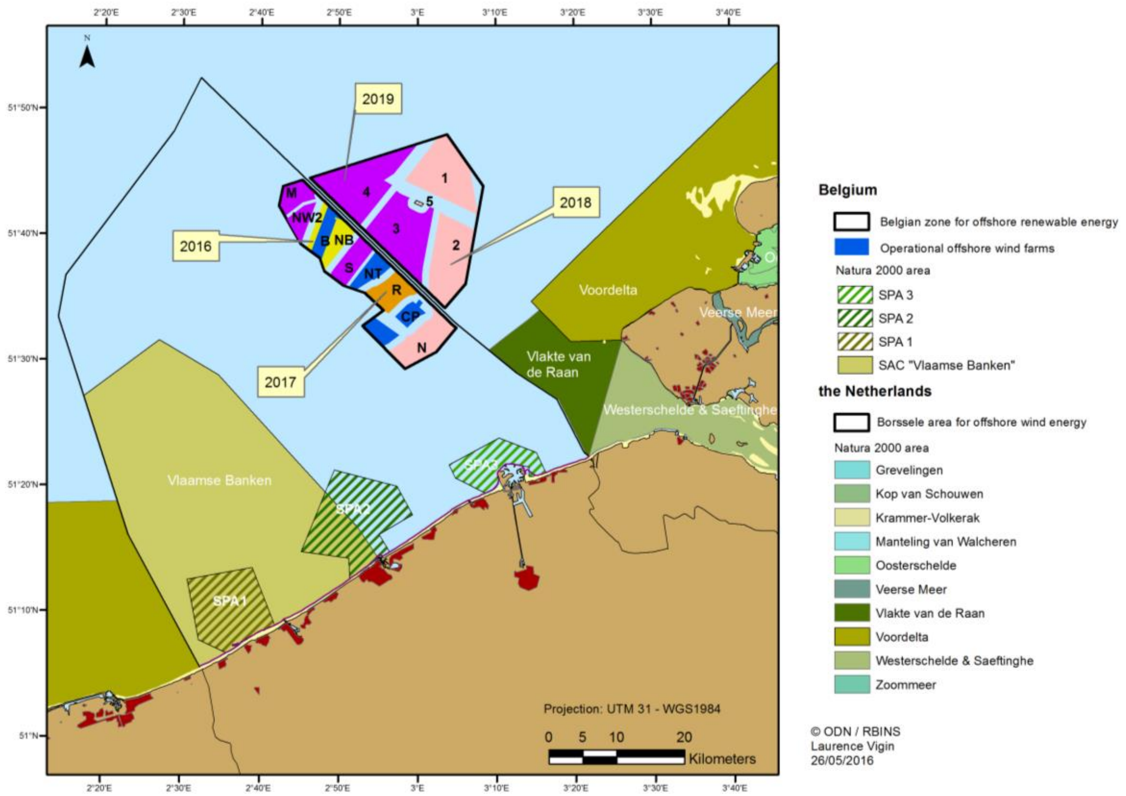

Figure 1. Map of the Belgian zone for offshore renewable energy, the Dutch Borssele offshore wind area and Natura 2000 areas in the vicinity. Already constructed wind farms are indicated in blue (CP: C-Power, NT: Northwind and B: Belwind); wind farms under construction in 2016 in yellow (NB: Nobelwind); in 2017 in orange (R: Rentel); in 2018 in pink (N: Norther, 1 and 2: Borssele 1 and 2); and in 2019 in purple (S: Seastar, NW2: Northwester2, M: Mermaid, 3 and 4: Borssele 3 and 4).

Table 1. Overview of the underwater noise regulations for wind farm construction in Belgium and the Netherlands (Borssele) (data Rumes et al., 2011; 2012; Ministerie van Economische Zaken, 2015)

	Belgian wind farm zone	Borssele
	Measures to limit or monitor the introduction of impulsive sound	
Noise restriction	Lz-p @ 750m: 185 dB re µPa	SEL @ 750m: 160-172 dB re µPa²s[1)]
Noise mitigation	Yes, if limit is exceeded	Yes, if limit is exceeded
Noise monitoring	Ad hoc inspections, by government	Continuous, by permit holder
	Measures to limit the impact of piling on marine mammals	
Seasonal piling restriction	No piling from January 1st to April 30th	No piling from January 1st till and including May 31st [2)]
Acoustic deterrent device	Yes, starts 30 min prior to piling	Yes, starts 30 min before piling
Piling starts with soft start	Yes	Yes
Marine mammal inspection prior to piling	Yes, by permit holder	No

1) As function of the number of turbines that is to be installed and the period of the year.
2) Only for projects with more than 76 wind turbines per single wind farm of ~350 MW

4.2 DATA SOURCES AND ANALYTICAL METHODS

Underwater noise levels were recorded at distances ranging from 250 m to 14 km from the pile driving location during the installation of steel monopiles (5.0 m diameter) at both the Bligh Bank (Belwind) and the Lodewijk Bank (Northwind), and of pin piles (1.8 m diameter) at the Thorntonbank (C-Power). Measurements of piling noise were performed using a Brüel & Kjær hydrophone (type 8104) which was deployed at a depth of 10 m, suspended from a drifting Rigid Hull Inflatable Boat (RHIB) (Norro et al., 2012). To avoid interaction with the hydrophone, the engine, radar and echosounder were turned off. For more details: see Haelters et al. (2009). Zero to peak sound pressure level (Lz-p SPL), unweighted SEL, cumulative SEL and 1/3 octave spectra were computed in order to quantify the underwater noise emitted during piling. These data were combined with SEL and SPL data aggregated by Bellmann (2014) to derive two functions which express SPL and SEL in relation to pile diameter in SPSS (IBM Corporation). Pile diameter was chosen since it is known well beforehand and both Parvin et al. (2006) and Betke & Matuschek (2010) previously found a proportionate increase in SPL with increasing pile diameter.

These functions were then used to extrapolate the anticipated underwater noise levels for the next two wind farms to be built in the Belgian wind farm zone: Rentel and Norther (Figure 1, Table 2).

Table 2. Characteristics of the planned Rentel and Norther wind farms (data Rentel and Norther, may be subject to change).

	Rentel	Norther
Anticipated period of piling	May to September 2017	May to September 2018
Foundation type	Monopile	Monopile (+ 1 Jacket for OTS)
Number of foundations	43	45
Pile diameter	7.2 – 7.8 m	6.5 – 8.0 m
Pile wall thickness	60 – 105 mm	60 – 90 mm
Noise restriction in permit	Lz-p @ 750m: 185 dB	Lz-p @ 750m: 185 dB

4.3 RESULTS

From a wide range of underwater noise measurements during pile driving work without noise mitigation systems (23 and 29 *in situ* measurements of SEL and SPL respectively with pile diameters between 0.7 and 6.0 m) two logarithmic trend curves were derived which express SPL and SEL as a function of pile diameter:

$$\text{SPL } L_{z\text{-}p} \text{ @ 750 m} = 181.8 + 10.536 \cdot \ln(\text{pile diameter in m}) \quad (R^2 = 0.73)$$

$$\text{SEL @ 750 m} = 158.7 + 11.124 \cdot \ln(\text{pile diameter in m}) \quad (R^2 = 0.78)$$

This is at best a rough approximation since other factors such as local geology, thickness of the pile wall, and hydraulic hammer energy also influence the noise levels generated during piling (Betke & Matuschek, 2010; Fricke & Rolfes, 2015).

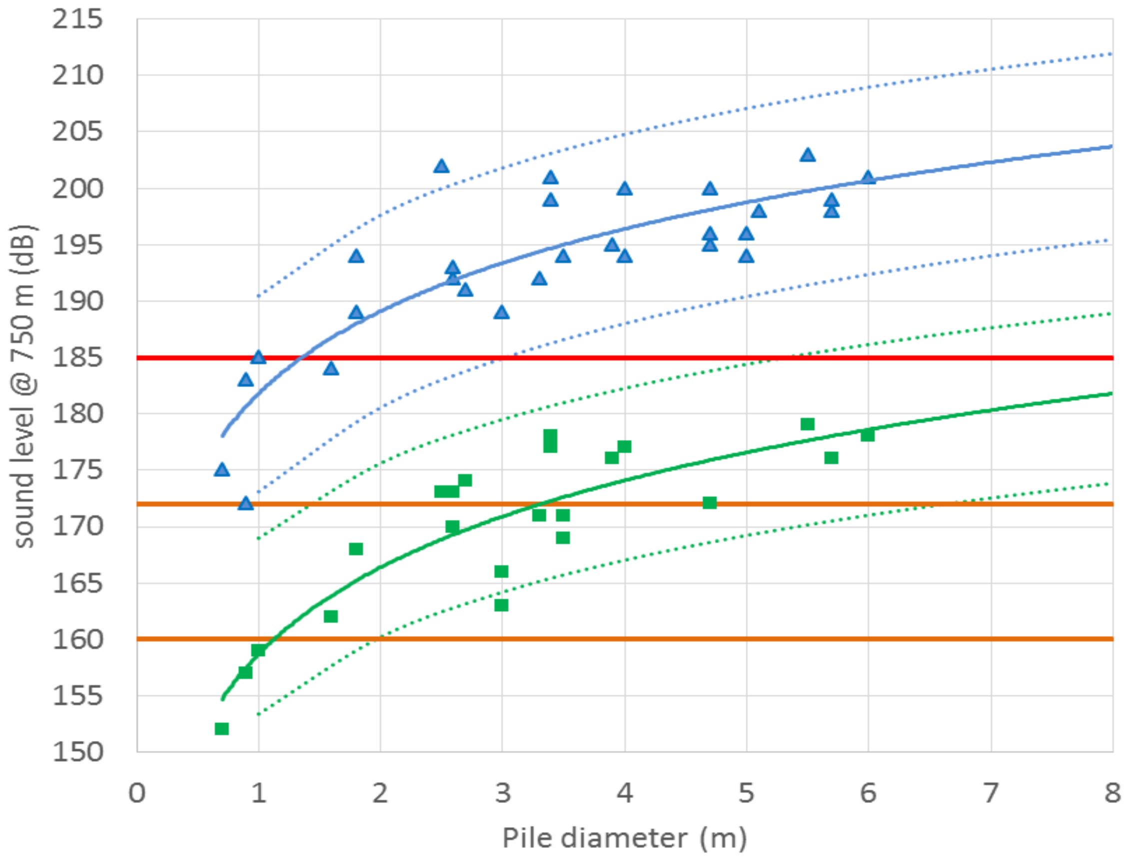

Figure 2. Zero to Peak Sound Pressure Levels (Lz-p @ 750m) (blue) and Sound Exposure Levels (SEL @ 750 m) (green) measured during pile driving as a function of pile diameter in relation to the Belgian Lz-p threshold (red) and the variable Dutch SEL threshold (orange – upper and lower end of range). 95% confidence intervals indicated by dashed lines (SEL and SPL data from Bellmann, 2014 and overview listed in Rumes et al., 2015).

If we apply these equations to the pile diameters foreseen in the as yet to be constructed wind farms we end up with a range of noise levels that exceeds both the Belgian and Dutch legislation by up to 19 dB (Table 3).

Table 3. Anticipated noise levels (Lz-p and SEL @ 750m) for the Rentel and Norther offshore wind farms and their relations to underwater noise thresholds for wind farm construction in Belgium and the Netherlands (Borssele).

	Rentel	Norther
Pile diameter	7.2 – 7.8 m	6.5 – 8.0 m
Anticipated noise level Lz-p @ 750m	203 dB	202 – 204 dB
Anticipated noise level SEL @ 750m	181 - 182 dB	180 - 182 dB
Minimal noise reduction to comply with Belgian limits	18 dB (Lz-p)	17 – 19 dB (Lz-p)
Minimal noise reduction to comply with Dutch limits*	18 – 19 dB (May) (SEL) 12 – 13 dB (June-August)	17 – 19 dB (May) (SEL) 11 – 13 dB (June–August)

* Not required by the Belgian environmental license

4.4 DISCUSSION

UNCERTAINTY REGARDING THE NOISE LEVEL EXTRAPOLATIONS

The logarithmic trend curves that were derived which express SPL and SEL as a function of pile diameter give at best a rough approximation since other factors such as local geology, thickness of the pile wall, and hydraulic hammer energy also influence the noise levels generated during piling (Betke & Matuschek, 2010; Fricke & Rolfes, 2015).

It should be noted that monopiles with diameters exceeding 7.0 m have yet to be installed, that noise mitigation systems have been used for the piling of all piles exceeding 6.0 m, and that the relation between pile diameter and noise levels thus remains uncertain for these XL (extra large) monopiles. As such, our estimates should be interpreted with considerable caution. However, it is clear that noise mitigation measures will need to be used to comply with conditions of the environmental license.

POSSIBLE NOISE MITIGATION MEASURES AND THEIR IMPACT

A wide range of noise mitigation systems has been developed and tested in offshore wind farms since Germany and Denmark both adopted piling noise level restrictions in 2012. These can be roughly categorized as bubble curtain systems, shell-in-shell systems, and others of which the Hydro Sound Damper and AdBm acoustic resonator are best documented.

A bubble curtain is formed around a pile by freely rising bubbles created by compressed air injected into the water through a ring of perforated pipes encircling the pile. Various types of bubble curtains exist (Little Bubble Curtains, Big Bubble Curtains, Double Big Bubble Curtains) and they are currently the most widely used techniques of noise mitigation. In Little Bubble Curtains (LBC) perforated pipes surround the pile in a close fit. LBC are less suitable in areas with strong currents as sound leakages may occur when bubbles drift away. A big bubble curtain (BBC) is a ring of perforated pipes positioned on the sea floor around the foundation to be piled. Compressors located on the construction vessel or on a platform feed air into the pipe. The air passes into the water column by regularly arranged holes. Freely rising bubbles form a large curtain around the entire structure, even during running tides, thus shielding the environment from the noise source (Koschinski & Lüdemann, 2013). Double Big Bubble Curtains (DBBC) add a second of ring of perforated pipes around a BBC. Noise reductions of 5 – 14 dB SEL, 10 – 15 dB SEL and 14 – 18 dB SEL have been found for LBC, BBC, DBBC respectively (Bellman *et al.,* 2015). Both the Rentel and Norther intend to deploy a Big Bubble Curtain (BBC) during piling to mitigate the impacts of excessive underwater noise (Figure 3). It is quite clear that a single noise mitigation measure, big bubble curtain, will in all likelihood not in itself suffice to comply with the national noise regulations. Koschinski & Lüdemann (2013) state that "a BBC is the best-tested and the most thoroughly proven noise mitigation technique for foundations of OWFs, but caution that certainty in noise reduction level cannot be guaranteed."

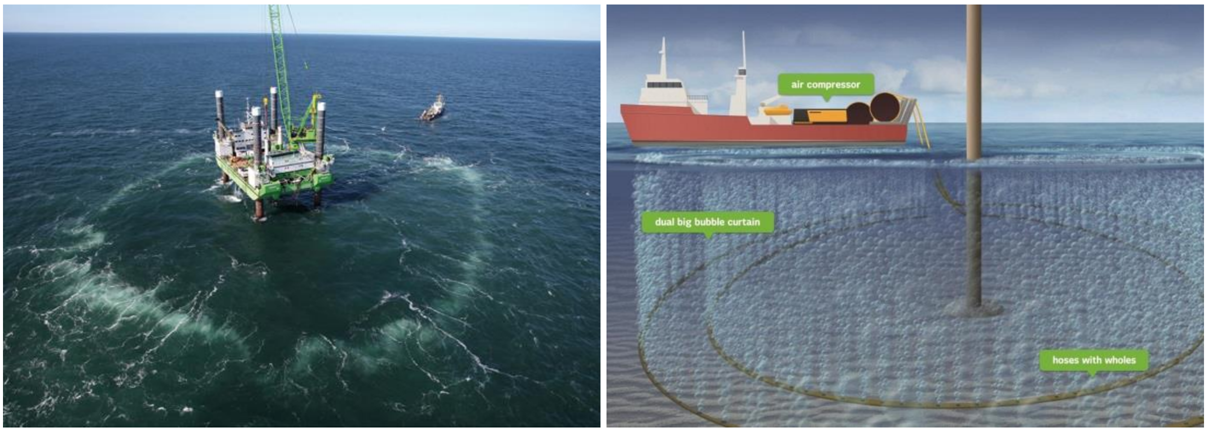

Figure 3. Left: Big Bubble Curtain in operation at Borkum West II. Note the presence of the BBC installation vessel (upper right corner) which also powers the compressors (Trianel GmbH). Right: Schematic of dubble big bubble curtain (DanTysk.com).

Shell-in-shell systems require encasing of the pile by an additional structure and thus reflect a part of the noise back inside. Various systems have been developed using additional layers containing air (foam, composites or bubbles freely rising inside) and the space between the pile and the casing can be water filled (with or without air bubbles) or dewatered. By combining several principles of noise reduction (shielding/reflection, absorption, scattering by air bubbles), shell-in-shell systems have a high theoretical noise reduction potential that is assumed to significantly exceed that of a BBC. They come however with a higher cost to developers as the heavy weight of most isolation casings requires a special design of the jack-up-rig, and as the time required to install the casing significantly increases construction time.

Hydro Sound Damper systems use fishing nets with air filled elastic balloons and special polyethylene foam elements with high dissipative effects to reduce continuous and impact noise (Elmer & Savery, 2014). Although this system is promising, with acoustic reductions of 9 dB (SEL) on average, and up to 15 dB Lz-p (Bruns *et al.,* 2014), it was not selected by the developers. It lengthens the construction time per pile because it needs to be fixed to the piles and doubts remain as to its application in an area with strong tidal currents. The AdBm Noise Abatement System consists of arrays of tuneable air-filled acoustic resonators which are deployed in a collapsible framework (Lee *et al*., 2014). Initial tests show acoustic reductions of up to 37 dB Lz-p for these air-filled acoustic resonators (AdBm, 2014) but a full scale field deployment has yet to take place.

Other measures which can be taken to reduce the noise levels generated during piling are directly related to the technical aspects of the piling operation. These include, but are not limited to, prolonging the pulse duration (Neuber & Uhl, 2012), reducing blow energy used (Bellman et al., 2015), and using an over-dimensioned pile driver at only 2/3 of its maximum power (Nehls et al., 2007). Although studies suggest that these measures, separately, all result in a fairly limited reduction of noise levels (Bellman et al., 2015), they have the advantage that they do not greatly impact construction timing and can be used in combination with other noise mitigation measures in order to comply with the legal noise limit. Rentel has indicated that an over-dimensioned pile driver and a reduction in blow energy will be used in addition to the BBC.

In The Netherlands the so-called BLUE Piling Technology is being developed. It uses the combustion of a gas mixture under a water column located in a reservoir on top of the pile to create a pressure increase which accelerates the water upwards and causes a downward force pushing the pile into the soil. The water column then falls back again, delivering a second blow. The exhaust gases are released and the cycle is repeated. This technology would deliver much lower noise levels than a conventional hydraulic hammer (www.fistuca.com).

4.5 FURTHER STEPS

A great deal of uncertainty still exists on both the anticipated underwater noise levels for piling of the XL monopiles as well as on the level of noise reduction that can be achieved by the measures currently being proposed by the Belgian wind farm developers. It is likely that a combination of noise mitigation measures will be needed to comply with national regulations. An in-depth underwater noise monitoring programme will be needed to determine the effectively produced noise levels.

In addition to underwater piling noise restrictions, both the Belgian and Dutch government have formulated a number of measures to prevent and limit the impact of piling noise on marine mammals. These include seasonally variable noise limits or restrictions, the use of acoustic deterrent devices prior to piling, and the use of a soft start procedure. All these measures are intended to minimise the number of marine mammals exposed to piling noise. Currently, these regulations are not streamlined and at times even contradictory for the Belgian wind energy area and the Dutch Borssele zone. For example, the seasonal piling restriction in the Borssele zone lasts up to the end of May rather than April for Belgian wind farms, but can be avoided if the 350 MW wind farm consists of more than 76 foundations. Developers and the marine fauna would benefit from the alignment of regulatory practices on a regional basis. As the Belgian and Borrsele wind farms are all located relatively close to each other, (partly) concurrent piling periods at multiple parks with similar noise restrictions will benefit the marine environment (as opposed to either consecutive piling periods or wildly dissimilar noise restrictions, which are in conflict with the noise restrictions in the neighbouring country).

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