Measures to reduce underwater noise and beach litter

An assessment of potential additional measures for the Netherlands

W.J. Strietman, R. Michels, E. Leemans

WAGENINGEN UNIVERSITY & RESEARCH

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1 Leemans Maritime Consultancy

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This report provides insight whether technologies are available that could be applied in the Netherlands if stricter regulations would be implemented to reduce impulsive underwater noise caused by pile driving and continuous underwater noise caused by shipping. Costs, benefits and the applicability of such technologies in the Netherlands are examined. Furthermore, a similar analysis is carried out for an hypothetical expansion of the MyBeach concept along the entire Dutch coast.

Dit rapport biedt inzicht of er technieken voorhanden zijn die in Nederland toegepast zouden kunnen worden indien er strenger beleid zou zijn om impuls onderwatergeluid bij heien en continu onderwatergeluid bij scheepvaart te verminderen. Daarbij wordt speciaal gekeken naar de kosten, baten en toepasbaarheid van dergelijke technieken in Nederland. Daarnaast wordt een vergelijkbare analyse uitgevoerd met betrekking tot de hypothetische uitbreiding van het MyBeach-concept langs de gehele Nederlandse kust.

Key words: underwater noise, pile driving, shipping, Marine Strategy Framework Directive.

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P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30,
E communications.ssg@wur.nl, http://www.wur.eu/economic-research. Wageningen Economic Research is part of Wageningen University & Research.

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Summary

S.1 Potential additional measures to further reduce impulsive underwater noise from pile driving at sea

1. In Germany, the current sound exposure norm is a single stroke sound exposure level (SEL_{SS}) of 160 dB at a distance of 750m to the construction. This norm is stricter than the one applied in the Netherlands. This level can be achieved using existing mitigation techniques. This shows that it is currently feasible to reach lower sound exposure levels with available techniques than those currently applied in the Netherlands.
2. Two of the most promising technologies that could be applied in the Dutch EEZ, if stricter regulation would be in place, are the Integrated Monopile Installer (IMI) and BLUE Piling technologies. When applying these noise mitigation technologies in combination with bubble curtains, the sound exposure level currently applied in German waters can be achieved, and quite possibly even lower levels.
3. The use of vibratory drilling and bubble curtains as standalone options are currently not feasible due to practical reasons, but could be used in combination with other technologies to reduce the sound exposure level.

S.2 Potential additional measures to reduce continuous underwater noise generated by shipping

1. Applying stricter regulations to reduce continuous underwater noise generated by shipping could potentially be applied in the Dutch EEZ in several ways. Examples of *technical solutions* are modified propellers, pod propulsion, wake improvement devices, optimisation of the foundation of the main engine and noise isolation between the engine and hull. Examples of *operational measures* are applying slower cruising speeds and better maintenance and cleaning of the propeller and hull. Examples of *economic instruments* that can be used to stimulate the use of these mitigation measures and technologies are programmes such as the Canadian EcoAction Program, aimed at rewarding voluntary action to reduce underwater noise in shipping. Adding underwater noise to existing programmes in the Netherlands (such as the Green Award and the Clean Shipping Index) could potentially provide an additional incentive for ship owners to take (voluntary) mitigation measures to reduce continuous underwater noise.
2. The Dutch maritime industry has a strong track-record in the field of underwater noise and shipping. Having stricter regulations or more voluntary measures in place could create extra opportunities for the Dutch maritime sector, more specifically companies and research institutes that have the expertise, skills and R&D capacity to provide the technical products and services needed to make such a transition work.
3. Having stricter regulations in place will also likely result in additional costs to certain shipping companies that have not (or are not willing to) install and apply mitigation measures. Shipping companies that do implement such measures may likely benefit (e.g. having lower port fees or creating a new customer base that support such initiatives).
4. If such stricter (voluntary or legislative) regulations are applied, creating a level playing field by applying the same measures at seaports throughout the North Sea or European region would be recommended. In such a situation, companies that take an effort in reducing underwater noise would be rewarded and the level playing field of large North Sea ports would not be distorted.
5. Through interviews with stakeholders, it became clear that there is a wish and opportunity to explore the possibilities of developing a common strategy by all stakeholders involved (e.g. research agenda, policy initiatives, collaboration projects, etc.).

S.3 Applying the Mybeach concept along the Dutch coast

1. To enable the calculation of a potential change in beach cleaning costs if the MyBeach concept would be applied along the entire Dutch coast, as much data as possible on beach cleaning costs were collected. The type and quality of data available, however, are not sufficient to make such a calculation. In particular, beach litter monitoring data on beaches with and without the MyBeach concept are lacking, as are detailed data on the costs of cleaning MyBeaches as opposed to 'regular' beaches.
2. As data on costs is lacking, it is not possible to calculate the costs and potential cost savings if this concept would be implemented along the entire Dutch coast. However, the implementation of the concept will likely result in a change in behaviour, which should result in cleaner beaches, less litter ending up at sea and lower beach cleaning costs to municipalities.
3. Currently, seven MyBeaches are fully operational along the entire Dutch coast, while four others are planned to be operational soon. As these locations are 'frontrunners' in adopting the MyBeach concept, there is still room to experiment what measures are effective.

S.4 Methodology

1. This report was commissioned by Rijkswaterstaat Water, Traffic and Environment. The aim of this report is to gain more insight into potential mitigation technologies and policy solutions relating to underwater noise and marine litter that could be applied if additional policy measures or stricter policy requirements would be implemented, specifically into their costs, benefits and applicability in the Netherlands.
2. The approach applied in this report is that preliminary costs and benefits, technical aspects, practicalities and applicability in the Netherlands of the solutions described are quantified as much as possible, depending on the available data. Where quantitative data is not available, this information is described in a qualitative way.
3. The information provided in this report is based on literature and interviews with experts and stakeholders. A list of consulted experts is available in Appendix 1.

Samenvatting

S.1 Potentiële aanvullende maatregelen om het impulsgeluid van heien op zee verder te verminderen

1. In Duitsland is de huidige ‘sound exposure’ norm een ‘stroke sound exposure level’ (SEL_{SS}) van 160 dB op een afstand van 750 m tot de installatielocatie. Deze norm is strikter dan de norm die in Nederland gehanteerd wordt en kan gehaald worden met bestaande mitigatietechnieken. Dit laat zien dat het momenteel haalbaar is om met bestaande technieken striktere normen te halen dan die momenteel in Nederland worden toegepast.
2. Twee van de meest kansrijke technologieën die toegepast zouden kunnen worden op het NCP zijn de Integrated Monopile Installer (IMI) en BLUE Piling. Indien deze technieken toegepast zouden worden in combinatie met bellenschermen, dan zou hiermee de norm gehaald kunnen worden die momenteel in Duitsland wordt toegepast, en waarschijnlijk zelfs lager.
3. Het gebruik van vibratory drilling of bellenschermen als enige in te zetten maatregelen is wegens praktische redenen op het NCP niet haalbaar. Deze technologieën zouden in combinatie met andere technologieën ingezet kunnen worden om een verdere reductie van de sound exposure level (SEL_{SS}) te realiseren.

S.2 Potentiële additionele maatregelen om continu onderwatergeluid van scheepvaart te verminderen

1. Het toepassen van strengere regelgeving om continu onderwatergeluid door scheepvaart te verminderen zou potentieel op verschillende manieren op het NCP gedaan kunnen worden. Voorbeelden van *technische oplossingen* zijn aangepaste scheepsschroeven, pod voortstuwing, kielzogverbetermiddelen, het verbeteren van de bevestiging van de hoofdmotor en geluidsisolatie tussen de motor en de scheepsromp. Voorbeelden van *operationele maatregelen* zijn langzamer varen en beter onderhoud en schoonmaken van de scheepsschroef en scheepsromp. Voorbeelden van *economische instrumenten* die toegepast kunnen worden om de inzet van deze mitigerende maatregelen en technieken te stimuleren zijn programma’s zoals het Canadese EcoAction Program, die erop gericht is om vrijwillige acties om onderwatergeluid te verminderen te belonen. Het toevoegen van onderwatergeluid aan bestaande programma’s in Nederland (zoals de Green Award en de Clean Shipping Index) zou potentieel een extra prikkel kunnen vormen voor scheepseigenaren om (vrijwillige) maatregelen te nemen on continu onderwatergeluid te verminderen.
2. De Nederlandse maritieme sector heeft een sterke track record op het gebied van onderwatergeluid en scheepvaart. Indien er strengere regelgeving of meer vrijwillige maatregelen worden toegepast, dan zou dit extra kansen bieden voor de Nederlandse maritieme sector, in het bijzonder bedrijven en kennisinstellingen die de kennis, kunde en R&D-capaciteit hebben om de technische producten en diensten te leveren die nodig zijn om een dergelijke transitie mogelijk te maken.
3. Strengere regelgeving zal waarschijnlijk ook leiden tot extra kosten voor bepaalde scheepvaartbedrijven die mitigerende maatregelen niet geïnstalleerd hebben of niet willen installeren. Scheepseigenaren die dergelijke maatregelen zouden nemen zullen hier waarschijnlijk van profiteren (in de vorm van lagere havengelden, of het creëren van een nieuwe klantenbasis die dergelijke initiatieven ondersteunt).
4. Indien er striktere wet- en regelgeving zou worden toegepast, dan zou het creëren van een level playing field voor zeehavens rondom de Noordzee of in Europese wateren door het toepassen van dezelfde maatregelen aan te bevelen zijn. In een dergelijke situatie zouden scheepseigenaren die maatregelen genomen hebben beloond worden en het level playing field van grote Noordzeehavens niet beïnvloed worden.

5. Op basis van interviews met stakeholders werd duidelijk dat er bij hen een wens bestaat om in dit dossier de krachten te bundelen en de mogelijkheden voor een gezamenlijke strategie voor alle betrokken stakeholders (onder andere op het gebied van kennisagenda's, beleidsinitiatieven, samenwerkingsprojecten, enzovoort) te verkennen.

S.3 Het Mybeach-concept

1. Voor de berekeningen in dit rapport hebben we zo veel mogelijk informatie verzameld over de schoonmaakkosten van stranden, om op die manier de potentiele reductie in schoonmaakkosten te berekenen indien het MyBeach-concept langs de gehele Nederlandse kust zou worden toegepast. De beschikbare gegevens zijn echter onvoldoende om een dergelijke berekening te kunnen maken. Met name monitoringsgegevens over afval op Mybeaches en daarbuiten ontbreken nog, evenals gegevens over de schoonmaakkosten van MyBeaches en 'gewone' stranden.
2. Omdat gegevens ontbreken is het niet mogelijk om de kosten en potentiële kostenbesparingen te berekenen voor een toepassing van dit concept langs de gehele Nederlandse kust. Echter, de toepassing van dit concept zal waarschijnlijk leiden tot een gedragsverandering met als gevolg schonere stranden, minder afval in zee en lagere schoonmaakkosten voor gemeenten.
3. Op dit moment zijn er langs de Nederlandse kust zeven MyBeaches operationeel, terwijl vier andere MyBeaches in de planning staan. Aangezien de huidige MyBeaches de 'koplopers' zijn, is er nog ruimte om te experimenteren en te bepalen welke maatregelen binnen het concept het meest effectief zijn.

S.4 Methode

1. Dit rapport is uitgevoerd in opdracht van Rijkswaterstaat Water, Verkeer en Leefomgeving. Rijkswaterstaat is geïnteresseerd in het verkrijgen van meer kennis over potentiële mitigatie technologieën en beleidsopties met betrekking tot onderwatergeluid en afval op zee die toegepast zouden kunnen bij eventueel strenger beleid. Hierbij gaat het om de kosten, baten en toepasbaarheid in Nederland.
2. De benadering die in deze studie wordt toegepast is dat de kosten, baten, technische aspecten, praktische zaken en toepasbaarheid in de Nederlandse situatie zoveel mogelijk kwantitatief beschreven worden, afhankelijk van de beschikbare gegevens. Waar er geen kwantitatieve gegevens beschikbaar zijn wordt de informatie kwalitatief beschreven.
3. De informatie in dit rapport is gebaseerd op literatuur en interviews met experts en stakeholders. Een lijst met geconsulteerde personen staat in bijlage 1.

1 Introduction

1.1 Background

The Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. GES means that the overall state of the environment in marine waters provides ecologically diverse and dynamic oceans and seas which are healthy and productive. In order to achieve GES by 2020, each Member State is required to develop a marine strategy and take measures if needed. Because the Directive follows an adaptive management approach, these Marine Strategies must be kept up-to-date and reviewed every 6 years (European Parliament, Council, 2008).

As part of the MSFD policy process, in December 2015 the Netherlands established its Programme of Measures (to reach GES). Based on an assessment carried out in 2017, it was concluded that due to the current and planned legislation and measures, GES is within reach (Ministerie van Infrastructuur en Waterstaat, 2018).

For some topics, such as underwater noise and marine litter, sufficient knowledge to define the current environmental status is lacking and therefore it is currently not known whether additional measures need to be taken. For these particular topics, the strategy by the Dutch government is to gain more knowledge (Ministerie van Infrastructuur en Waterstaat, 2018). As part of this strategy, the Ministry of Infrastructure and Water Management is interested in gaining more insight into potential mitigation technologies and policy solutions that could be applied if additional policy measures or stricter policy requirements would be implemented, specifically into their costs, benefits and their applicability in the Netherlands.

1.2 Aim

The aim of this report is to provide insight into the costs, benefits and applicability in the Netherlands of technological and policy solutions that could potentially be applied if stricter policy or legislative requirements would be implemented in relation to impulsive underwater noise during pile driving, continuous underwater noise in shipping and beach litter. In relation to both impulsive and continuous underwater noise, the focus in this report will be on mitigation technologies which are currently available on the market or will be soon become available. With regards to reducing beach litter, the focus will be on the application of the MyBeach concept along the entire Dutch North Sea coast.

1.3 Method

The approach applied in this report is that preliminary costs and benefits, technical aspects, practicalities and applicability in the Netherlands of the solutions described are quantified as much as possible, depending on the available data. Where quantitative data are not available, this information is described in a qualitative way. The information provided in this report is based on literature and interviews with experts and stakeholders. A list of consulted experts is available in Appendix 1.

2 Overview of technologies that could further reduce impulsive underwater noise from pile driving at sea

2.1 Introduction

For all windfarms in the Dutch part of the North Sea (EEZ), monopiles are used as the foundation of windturbines. So far, all monopiles have been drilled using a hydraulic hammer. This type of technology involves a method that, without mitigation measures, would generate such impulsive underwater noise levels that this would negatively impact the Harbour Porpoise population in Dutch waters. Therefore, the Dutch government has adopted a regulation that describes the maximum allowed amount of sound, depending on season and number of piles to be driven (Ministerie van Infrastructuur en Waterstaat, 2018).

This chapter examines whether noise mitigation technologies are, or will become available that, when applied, can reach levels that would go beyond the requirements of current legislation, and which might be applied if stricter laws on impulsive underwater noise would be decided. Based on desk research and interviews with experts, several technologies are examined to determine their potential effect on the reduction of impulsive underwater noise, their applicability in the Dutch EEZ and their costs (where data are available).

When reading this chapter, please keep in mind that with every reduction in sound of 3 dB, the amount of sound energy is halved, since dB is expressed on a logarithmic scale.

2.2 Policy context

During the last couple of years, the number of planned offshore windfarms has increased significantly. Currently, five windfarms at sea are in use: Offshore Windpark Egmond aan Zee (OWEZ), the Prinses Amalia Windpark, Luchterduinen, Buitengaats and ZeeEnergie (also known as the Gemini Windparks). In total, these windfarms generate 957 MW (Noordzeeloket, 2018).

In 2014, three more locations were designated where windfarms can be developed: Borssele, Hollandse Kust (south) and Hollandse Kust (north). In addition, in 2018, the government announced its plans to enable the development of more windfarms, with a total capacity of 7,000 megawatt (Noordzeeloket, 2018). These windfarms are planned to be in use between 2024 to 2030. As a result of these plans, an increase in construction activities (and accompanying underwater noise) at sea is expected. All current and planned windfarms are shown in Figure 2.1.

Without noise reduction techniques, the single stroke sound exposure level (SELss) using conventional hydro-hammer techniques with energies up to 1 MJ are in the order of magnitude of 165-175 dB at 750 m range in 25-30 m water depth (TNO, 2016).

The Dutch government has concluded that constructing new offshore windfarms using conventional (hydro-hammer) techniques (without mitigation measures) would result in unacceptable effects on the Harbour Porpoise population and mitigation measures need to be taken. This knowledge is currently incorporated into legislation, such as the Wind Energy at Sea Act (Ministerie van Infrastructuur en Waterstaat, 2018).

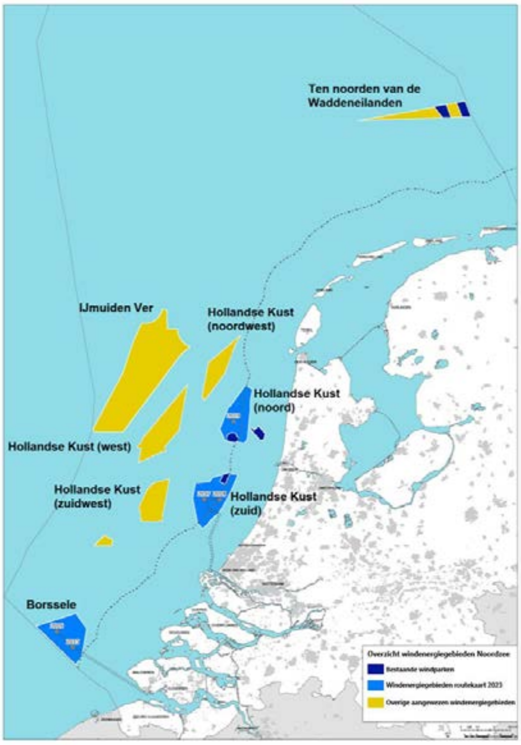

Figure 2.1 *Current and planned windfarm locations on the Dutch EEZ*
Source: Noordzeeloket (2018).

As part of the Wind Energy at Sea Act (Rijksoverheid, 2018), the plot decrees for the planned wind farms stipulate amended conditions for pile-driving for wind farms with a view to reducing noise levels. These conditions include a maximum amount of emitted sound, with the level being based on the building season and the number of piles to be driven. In this way, the maximum SEL_{SS} at a distance of 750m to the construction site permitted in the Netherlands varies between 159 and 172 dB depending on the number of piles (Rijksoverheid, 2018).

On a European level, regulations regarding sound emissions vary. For example, in Germany the norm for the maximum SELss is set at 160 dB at a distance of 750m to the construction site. This norm is stricter than the on applied in the Netherlands.

2.3 Current environmental status (MSFD)

The Good Environmental Status (GES) for impulsive noise (D11C1) in Dutch waters is achieved if the spatial distribution, length of time and noise levels of loud impulsive sources are at such a level that the direct and indirect effects of loud impulsive noise do not endanger the favourable conservation status of protected species (Ministerie van Infrastructuur en Waterstaat, 2018).

It is currently not known if GES is reached because only one year with sufficient data is available (2015), and the situation might vary from year to year. It is, however, expected that because of the stricter regulations in place since 2015, GES will be reached in 2020 (Ministerie van Infrastructuur en Waterstaat, 2018).

2.4 Foundation techniques for pile driving

2.4.1 Introduction

A developer of an offshore wind farm chooses among different foundation technique options. The choice for a foundation technique usually depends on the local water depth, local soil conditions, expected construction time of the foundation and costs of each option. Because of the average water depth at the designated areas in Dutch EEZ, the large-scale experience by contractors and efficiency, monopile driving is expected to be the most appropriate and feasible foundation method in the near future (Royal HaskoningDHV, 2015).

2.4.2 Examined technologies

In this chapter we specifically examine several relatively new monopile driving technologies that could potentially be applied in Dutch waters and may contribute to a further reduction in impulsive underwater noise levels:

1. Integrated Monopile Installer/IHC Hydrohammer
2. BLUE Piling
3. Vibratory drilling
4. Bubble curtains

2.5 Integrated Monopile Installer

2.5.1 Description

The Integrated Monopile Installer (IMI) was developed by the Dutch company IHC IQIP and encompasses several features that focus on reducing noise levels and operational time, increasing accuracy and creating a safer working environment. The system also includes components for inclination and rotation of the monopile (see Figure 2.2). All elements together are integrated into one system that safeguards against the impact from waves and currents (IHC IQIP, 2017). Using this system, it is possible to install one monopile a day (Jung, 2017, pers. comm.).

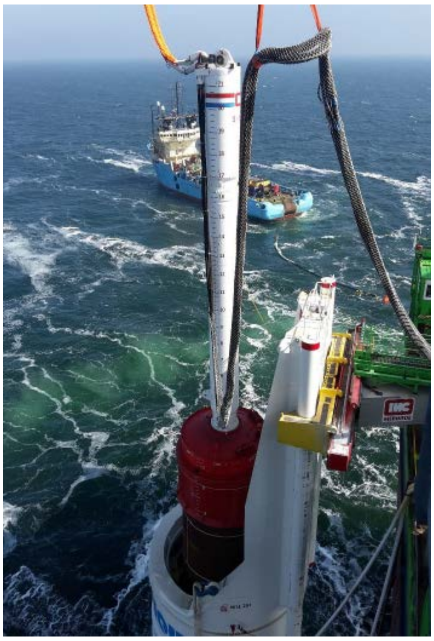

Figure 2.2 *The Integrated Monopile Installer*
Source: IHC IQIP (2017).

In terms of noise reduction, the IMI combines features of an isolation casing with those of a confined bubble curtain by using both a double-wall isolation casing with an air filled interspace (air isolated barrier) and an adjustable multi-layered bubble curtain between the noise mitigation system and the pile (IHC IQIP, 2017).

2.5.2 Effects

Based on measurements in waters of up to 23m in Germany on piles with a diameter of 5.7m., it was concluded that using this technique, the maximum SEL_{SS} at a distance of 750m to the construction site can be reduced from 180 dB to 163 dB. These measurements show that the system is suitable to achieve a considerable noise reduction during pile driving of large monopiles (Koschinski and Lüdemann, 2013). With the additional application of bubble curtains outside of the IMI, it is possible to reduce noise transmitted through the sediment ('leaking' from the seabed around the monopile foundation) and achieve a SELss of less than 160 dB (Tsouvalis, 2015).

2.5.3 Applicability

Since 2012, this technology (IMI) has been applied in six German offshore windfarms on more than 350 monopiles (Jung, 2017, pers. comm.), but, as of yet, not in the Dutch EEZ. In this way, the IMI can be considered to be a proven technology.

2.5.4 Costs/benefits

In comparison to a conventional monopile installation device, the Integrated Monopile Installer combines multiple functionalities in one piece of equipment. By integrating these functionalities, it is claimed that the installation process takes less time (one day for each monopile) than the installation of a monopile using conventional technologies, there are fewer safety risks involved and the costs are reduced (Jung, 2017, pers. comm.). Detailed financial information about the costs or savings of this technology are not publicly available.

2.6 BLUE Piling

2.6.1 Description

BLUE Piling Technology is a relatively new technology for driving large piles offshore and is developed by the Dutch company Fistuca BV. The technology is designed in such a way that it minimises both underwater noise and metal fatigue.

The technology is based on a different technique to drive monopiles into the soil than conventional pile driving techniques: instead of the steel ram used by conventional hammers, it utilises (the weight of) a column of water that goes up and down to drive a pile into the soil. A combustion throws up this water column, which falls back on the pile under the force of gravity (see Figure 2.3). The properties of water mean that this deceleration occurs over a longer time period than a conventional hydraulic hammer, providing a quieter, gentler but more energetic blow. This cycle is repeated until the pile reaches the desired depth (Winkes, 2017, pers. comm.).

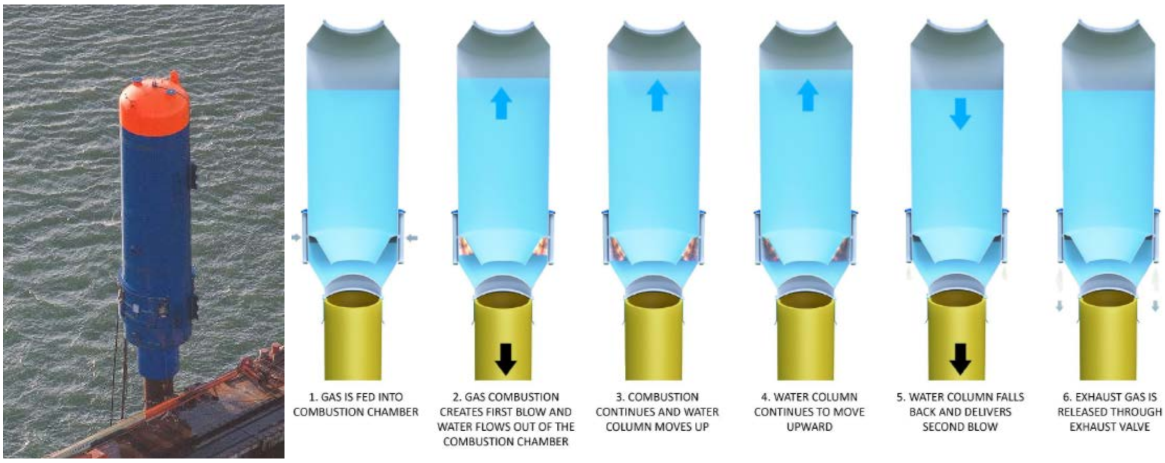

Figure 2.3 *Working principle of BLUE Piling technology (Fistuca, 2017)*

2.6.2 Effects

BLUE Piling technology is relatively new. It has been tested in a harbour basin and will be tested at sea in June 2018. TNO was and will be involved in both trials to measure underwater noise levels. The measurements of the first trial suggest that the BLUE pile driving method has the potential to provide a more silent pile driving technique than conventional impact pile driving methods with hydraulic (hydro) hammers (TNO, 2016).

2.6.3 Applicability

This technology has not been applied yet during the construction phase of windfarms. After trialling a prototype in 2016, Fistuca is planning to trial a full-size hammer, capable of driving the largest monopiles currently available in the market, in the Dutch EEZ in June 2018. If the results of these trials are positive as well, the new hammer will be available for rent afterwards (Winkes, 2017, pers. comm.).

2.6.4 Costs/benefits

The developer claims that the costs of producing this system are similar to a conventional hydraulic hammer. However, other costs are claimed to be lower:

- As mentioned earlier, in Europe, Germany applies the strictest underwater noise standards: The costs of monitoring and the application of mitigation technologies to reduce underwater noise have been calculated to be around 10-15% of the installation costs (Schorcht, 2015) or €10-30m for each windfarm (RoyalHaskoningDHV, 2015). Since it is claimed that this technique would make the use of additional mitigation measures unnecessary, this would theoretically result in a cost reduction of 10-15% or €10-30m for each windfarm, compared to conventional techniques;
- Due to an anticipated reduction of 85-98% on installation fatigue, it is envisaged that this technology may enable boat landings or ladders to be pre-welded to the monopile before installation, thereby simplifying the process and cutting costs (Fistuca, 2017);
- Faster installation time of foundations, reducing pile driving time by up to 70% in comparison to a conventional hydro hammer (Fistuca, 2017).

2.7 Vibratory pile driving

2.7.1 Description

Vibratory pile driving is a technique where a vibratory hammer is used instead of an impact hammer. The vibratory hammer makes the pile oscillate, resulting in liquefaction of the soil, enabling penetration into the seabed. This technique is commonly used on land and sometimes at sea (Royal HaskoningDHV, 2015). In terms of underwater noise, vibratory driving produces continuous sound (as opposed to impulsive sound, which is the result of hammering).

2.7.2 Effects

During the construction phase of the Alpha Ventus windfarm, a vibratory pile driver was applied in combination with a conventional impact pile driver to anchor the tripods for six turbines. The foundation piles had a diameter of 2.6 m and the embedment depth was about 30 m. According to Koschinski and Lüdemann (2013), by means of the vibratory pile driver, only the initial meters (maximum 9 m) could be driven into the ground. The additional meters had to be drilled using a conventional pile driving method.

The underwater sound exposure levels during vibratory drilling varied during this period between 142 and 157 dB SEL at 750 m distance (Koschinski and Lüdemann, 2013). These sound exposure levels were substantially lower than the sound exposure levels of the impact pile driver (applied afterwards) of 167 dB SEL. In the 2013 study by Koschinski and Lüdemann, the conclusion was reached that if only a part of the overall embedment depth can be reached by vibratory pile driving, the number of impact piling strikes required to reach the final mounting would still be reduced, which in turn would diminish the impact zones for marine mammals and fishes during the construction phase of windfarms (Koschinski and Lüdemann, 2013).

Please note, however, that the measurements mentioned by Koschinski and Lüdemann have been conducted on piles with a diameter of 2.6m, much smaller than the diameter of piles used for windfarms at sea. Therefore it is not known if these numbers would be similar in conditions with larger pile diameters such as the ones used in the Dutch EEZ.

2.7.3 Applicability

This technology is still being improved and tested by contractors and is not expected to be applied on a large scale on the North Sea soon as the sole technology to drive piles for offshore windfarm. There are two main reasons for this:

1. There is uncertainty whether a monopile foundation is stable enough by vibrating only. Therefore research is being carried out to collect information on the lateral load bearing capacity of a pile vibrated to full installation depth (MPM Research Community, 2018).
2. Vibro driving has proven to be effective in the upper soil layers and in sandy layers, where sediments are usually less compact than in deeper layers. Applying this technology would therefore avoid pile strikes of comparatively lower energy in the upper soil layers, while for the deeper (more compact) soil layers, louder blows are still necessary. Although the number of blows at high energy may be lower, the net effect on reducing the disturbance to marine animals may be limited (Dekeling, 2017, pers. comm). It is also much less appropriate in clay soil, a soil type commonly present throughout the Dutch EEZ (Koschinski and Lüdemann, 2013), (Royal HaskoningDHV, 2015).

As mentioned before, vibratory pile driving is primarily used to penetrate the upper meters of the seabed, where sediments are usually less compact than in deeper layers. Applying this technology would therefore avoid pile strikes of comparatively lower energy, while for the deeper (more compact) soil layers, louder blows are still necessary.

If applied in the Dutch EEZ, due to prevailing soil conditions not all piles can be driven up to the required embedment depth using vibratory drilling alone. Additional hammer drilling may therefore (still) be needed. Hence, an exclusive application of vibratory pile driving is not possible. As such, it is currently not a proven technology that can be applied as the sole technology to drive piles for offshore windfarms in the Dutch EEZ. However, vibratory pile driving *in combination with* impact pile driving is a proven technology (Koschinski and Lüdemann, 2013).

2.7.4 Costs/benefits

For this report, it has not been possible to obtain sufficient data on the costs of this technology and requires further study.

2.8 Bubble curtains

2.8.1 Description

A bubble curtain is a sheet or 'wall' of air bubbles that is produced around the location where pile driving occurs. Air bubbles in water create a change in the speed of sound through water that is effective in blocking noise transmission from the noise source. The bubbles are created by forcing compressed air through small holes drilled in metal, PVC rings or hoses. This technology either uses freely rising air bubbles or bubbles contained in an additional casing around the area of rising air bubbles. The latter type of system is designed to cope with currents in order to maintain a closed shield of bubbles. Air compressors are usually located on the construction vessel or on a nearby platform, from which they feed air into the air bubble system (Koschinski and Lüdemann, 2013).

2.8.2 Effects

This technology is a proven technology to reduce underwater noise in certain conditions. Several studies have been carried out into the effectiveness of bubble curtains during pile driving for wind turbine foundations. Based on the results of these studies, it turns out that the effectiveness of this technology is highly dependent on the local conditions, especially currents and depth (it is less effective with high currents and in deeper waters).

According to Koschinski and Lüdemann (2013), the application of a big bubble curtain or a double bubble curtain makes it possible to meet the (German) 160 dB threshold level up to certain impact energy (depending e.g. on pile diameter) and for certain environmental conditions and works best in combination with other noise reducing technologies. This technology can therefore be considered to be a proven technology to reduce underwater noise.

2.8.3 Applicability

Bubble curtains exist in different configurations and work best in shallow locations. As mentioned earlier, the effectiveness of this technology is highly dependent on the local conditions (especially currents and depth). In deep(er) water locations, (strong) currents can pull the rising air bubbles to the side instead of straight up, resulting in a highly dispersed bubble curtain which is less effective.

Due to the fact that sound in deeper waters is transmitted at a further distance, a more extensive bubble curtain is required (Royal HaskoningDHV, 2015). In cases where a higher noise reduction is required (e.g. for large monopiles) a double bubble curtain offers an even higher reduction potential (Koschinski and Lüdemann, 2013). The additional level of reduction is also dependent on the local conditions.

The application of a bubble curtain system also usually requires a separate vessel in addition to the installation vessel for the storage of power packs and air pumps/compressors. However, the application of these devices on board a ship may be limited by the wave height. According to Koschinski and Lüdemann (2013), in the case of large movements of the ship, problems may occur with the suction process of the oil and the devices could be automatically shut-down. This may cause time delays in the monopile installation procedure.

2.8.4 Costs/benefits

A major share of the costs of bubble curtain technology is related to the supply of compressed air to the bubble curtain(s). This process involves power packs and air pumps, and the use of a separate vessel. The more bubbles are necessary (i.e. due to water depth or the amount of bubble rings), the higher the costs.

The average cost of using a bubble curtain is estimated to be around €100,000 for each day or monopile foundation (CSA Ocean Sciences Inc., 2014), but the actual costs can be considerably higher, depending on the amount of bubbles needed and the size of the system involved.

This technology is still evolving and in the near future, costs might be lower as a result of this.

2.9 Discussion

In this chapter, we examined whether noise mitigation technologies are, or will become available that, when applied, can reach levels that would go beyond the requirements of current legislation, and which might be applied if stricter laws on impulsive underwater noise would be in place. Based on desk research and interviews with experts, several technologies were examined to determine their potential effect on the reduction of impulsive underwater noise, their applicability in the Dutch EEZ and their costs (where data are available).

From Table 2.1, it can be seen that noise mitigation technologies are, or will likely become available that can be applied in the EEZ to reach stricter (lower) noise levels than currently required by law, whether temporarily (e.g. during certain months or in a location where the cumulative effects of additional drilling would be considered too high) or permanently. Realising lower levels than required by law in the Netherlands has already been achieved in German waters, where stricter noise regulations apply.

Table 2.1 *Effects, applicability and costs of four measures*

Type of measure	Effects	Applicability	Costs
1. Integrated Monopile Installer	With this technique, on a pile with 5.7m diameter, a SEL of 163 dB at 750m can achieved. With the addition of bubble curtains, less than 160 dB.	This is a proven technology which has been applied in German waters and can be applied in the Dutch EEZ.	It is claimed by the manufacturer that the installation process takes less time than the installation of a monopile using conventional technologies, and in this way reduces costs. Information about the costs or savings of this technology are not publicly available.
2. BLUE Piling	The underwater noise levels of this technology will be tested at sea in June 2018. During trials in a harbour basin, the sound levels produced were below the maximum noise level currently applied in German waters (160 dB).	This technology has not yet been applied during the construction phase of windfarms. A full-size hammer, capable of driving the largest monopiles currently available in the market will be tested at sea in June 2018. If the results of these trials are positive, the new hammer will be available for rent afterwards.	Due to the expected cost savings in comparison to conventional techniques, it is claimed that this technology could potentially produce lifetime savings of up to 10-15% or €10-30m compared to conventional techniques, for an average windfarm.
3. Vibratory drilling	On a pile with 2.6m diameter, the underwater sound exposure levels during vibratory drilling varies between 142 and 157 dB at 750 m distance.	Vibratory pile driving in combination with impact pile driving is proven technology in certain soil conditions. If applied in the Dutch EEZ, an exclusive application of vibratory pile driving is not possible.	For this report, specific data on costs and benefits of vibratory drilling could not be obtained and requires further study.
4. Bubble curtains	The application of a big bubble curtain or a double bubble curtain makes it possible to meet the (German) 160 dB threshold level in certain conditions. Its effectiveness is highly dependent on local conditions, especially on the strength of currents and depth (it is less effective with high currents and deeper waters). It works best in combination with other noise reduction technologies.	Bubble curtains exist in different configurations and work best in shallow locations. In deep(er) water locations, (strong) currents can pull the rising air bubbles to the side instead of straight up, resulting in a highly dispersed bubble curtain which is less effective. In those cases, a more extensive bubble curtain is required. The application of a bubble curtain system requires a separate vessel or vessels for the storage of power packs and air pumps and compressors. The more bubbles are needed, the more storage area is needed.	The costs of applying this technique are mainly related to the costs of supplying compressed air to the bubble curtains: the more bubbles, the higher the costs. The average cost of using a bubble curtain is estimated to be around €100,000 for each day or monopile foundation, but the actual costs can be considerably higher, depending on the amount of bubbles needed and the size of the system involved. This technology is still evolving and in the near future, costs might be lower as a result of this.

3 Technologies and measures to reduce underwater noise generated by shipping

3.1 Introduction

Every self-propelled ship produces (continuous) underwater noise. The intensity of noise depends on the operating conditions and ship design. The main sources of continuous noise in shipping are the propeller and the engine. Since shipping has increased substantially during the last couple of decades, so has continuous underwater noise. This has contributed to a large global noise footprint and subsequent impact on the marine environment. One example of such an impact is so-called ‘masking’, where continuous underwater noise overlaps with sound produced and used by sea mammals (Erbe, Reichmuth et al., 2016).

In this chapter, several noise mitigation technologies and economic instruments are examined that could potentially be applied in the Netherlands if stricter laws on continuous underwater noise would be in place. For this examination, three types of potential measures have been assessed: technical and operational measures and economic instruments. Based on desk research and interviews with experts, these types of measures are examined to determine their potential and effects to different stakeholder groups in the Netherlands.

3.2 Policy context

As more knowledge is becoming available on both the presence of continuous underwater noise generated by ships and the effects of it, the first steps are taken on an international level to work on solutions and policy measures. Within the Marine Strategy Framework Directive, one of the descriptors of Good Environmental Status is continuous noise (see paragraph below). IMO has also started to address this topic and has developed non-mandatory guidelines in 2014 (IMO, 2014). These guidelines are intended to provide general advice about reduction of underwater noise to designers, shipbuilders and ship operators.

In comparison to knowledge about the (direct) effects of impulsive noise, knowledge on continuous noise levels in different situations, time periods and environments is scarce. A comprehensive and current overview of knowledge available has been collected and examined in the AQUO/SONIC project[1]. Another relevant project is Baltic Sea, and is the first comprehensive dataset in a European region describing underwater sound levels.

One of the programmes the Dutch government is coordinating is the ‘Joint Monitoring Programme for Ambient Noise in the North Sea’ (JOMOPANS), which aims to generate soundscape maps for the North Sea (JOMOPANS). By participating in the JOMOPANS project, the Dutch government is gaining more knowledge on the levels of continuous underwater noise in the marine environment, which is needed (but not sufficient) in order to be able to decide whether and which type of (additional) measures are needed during the next MSFD policy cycle in 2024 (Ministerie van Infrastructuur en Waterstaat, 2018).

When more knowledge becomes available in the future, objectives on background noise may potentially be set, aiming to prevent effects on populations or the ecosystem (Ministerie van Infrastructuur en Milieu, Ministerie van Economische Zaken, 2015).

[1] www.aquo.eu

Since worldwide (IMO) legislation and regulations to mitigate continuous underwater noise by shipping are currently not in place (and non-mandatory), noise mitigation measures are only applied in certain situations or for specific purposes. In the Netherlands, no such measures are in place. However, if in the (near) future, knowledge becomes available that would show that action is needed to mitigate against the effects of (continuous) underwater noise on populations or the ecosystem, developing and adopting guidelines on IMO level will likely be supported by the Dutch government (Ministerie van Infrastructuur en Milieu, Ministerie van Infrastructuur en Water, 2018).

A potential sign of things to come, is that in June 2018, the United Nations Informal Consultative Process addressed the theme of anthropogenic underwater noise. As much of the discussion was on continuous underwater noise from shipping, it is expected that in the near future the IMO (and parties within the IMO) will put more attention on continuous noise and commercial shipping as the most important source of continuous noise (United Nations, 2018).

3.3 Current environmental status (MSFD)

The GES of continuous underwater noise (D11C2) is described as: the spatial distribution, timeframe and levels of background noise is at such a level that it will not have adverse effects on marine ecosystems (Ministerie van Infrastructuur en Waterstaat, 2018). It is currently not possible to define a quantitative description for continuous underwater noise because data on the levels and trends in continuous noise are not available yet (Ministerie van Infrastructuur en Waterstaat, 2018).

3.4 Cavitation reducing technologies

3.4.1 Description

The most important source of continuous underwater noise in shipping is cavitation. Cavitation is the name of the process where water behind rotating propeller blades forms vacuum bubbles. As the bubbles leave the blades, the pressure around these bubbles changes, causing the bubbles to implode and pop violently in a continuous way. Therefore, in order to decrease propeller radiated noise, cavitation has to be reduced (AQUO Consortium, 2015).

Cavitation exists in different types. Therefore, there is no single solution to reduce the effects of cavitation. Reducing one type of cavitation could also act counterproductive to mitigate other types of cavitation. The effectivity of the technology applied is therefore highly dependent on the type of cavitation, the type of ship, the type of propulsion, etc. (Keizer, 2017, pers. comm.).

There are several technological solutions to reduce the noise generated by cavitation. This could be possible by either improving the wake inflow to the propeller or by improving the propeller design. Such modifications to the propeller or stern such as spoilers or fins can be fitted to new and existing ships (AQUO Consortium, 2015). One of the options to modify the geometry of the propeller is to use larger propellers and/or more blades. A larger, slow revolving, propeller produces less underwater noise and could also be more fuel efficient than smaller propellers (Keizer, 2017, pers. comm.).

Another technology that produces less cavitation is pod propulsion. Pods are electric propulsion devices which combine both propulsive and steering functions in one device and are usually located below the stern of a ship. Since it is located outside of the ship, directly in the water, there might be more engine noise coming from the electromotor in the pod (with different sound characteristics than cavitation) (De Jong, 2017, pers. comm.).

3.4.2 Effects

All of the solutions mentioned in this section reduce underwater noise levels, although the amount varies, depending on the type of solution. Some of these solutions also have an effect on energy efficiency, where they reduce the amount of fuel needed for propulsion. In fact, energy savings might be the prime reason to apply these solutions, and reduced underwater noise a positive side-effect. It should be noted, that when aiming for improved energy efficiency, the optimal propeller configuration might not be the same as for underwater noise.

3.4.3 Applicability

Some of the solutions mentioned in this section entail fundamental changes to the ship and can only be done when building new ships (e.g. installing pod propulsion). Other adjustments can only be done when the ship is dry-docked every couple of years (e.g. installing a new propeller).

In terms of their suitability at sea, some solutions, such as changing the configuration of the propeller might be suitable in some situations, but not all. Changing the configuration usually means adjusting the size and shape of the blades. Larger blades might stick out underneath the hull, making them more prone to the risk of damage due to contact with the seabed or sea-ice (De Jong, 2017, pers. comm.; Keizer, 2017, pers. comm.).

3.4.4 Costs/benefits

For this report, it has not been possible to obtain sufficient data on the costs of these technologies. It is known though, that modifications and adjustments to ship's propeller to reduce continuous underwater could go hand in hand an improvement of energy efficiency. In this way, a retrofit or upgrade of the propulsion system may also bring savings in fuel costs (Bosschers, 2017, pers. comm.). It is not known what these savings would amount to.

3.5 Bubble curtains and engine noise insulation

3.5.1 Description

Some other technologies could also be helpful to reduce continuous underwater noise. In this paragraph we will describe several examples, including wake improvement devices, bubble curtain technology, optimising the foundation of the engine, applying noise insulation around the engine and more effective maintenance.

A relatively simple adjustment to the ship is formed by *wake improvement devices* such as spoilers or fins. These can be fitted to new and existing ships during drydocking (AQUO Consortium, 2015).

Bubble curtain technology could be applied to reduce drag by injecting air bubbles into the cavitation, thereby neutralising the vacuum bubbles. When needed, such a system can be switched on or off, for example while cruising through a sensitive area (Bosschers, 2017, pers. comm.; Keizer, 2017, pers. comm.).

To reduce noise coming from the main engine, and travelling through the hull, options could be to *optimise the foundation of the main engine or apply noise insulation* between the engine and hull (Bosschers, 2017, pers. comm.).

A reduction in continuous underwater noise could also be achieved by a *more effective maintenance of the propeller and/or the hull*. This could be done either by repairing damages or removing fouling. These maintenance improvements will not result in major reductions in underwater noise, but might be one of the contributing factors. Regular hull and propeller maintenance will also improve fuel efficiency, since by decreasing the frictional resistance of hull and/or propeller the same vessel speed can be maintained with less propulsion power (AQUO Consortium, 2015).

3.5.2 Effects

The effects of the solutions mentioned above vary, depending on the type of solution. All of the solutions influence noise levels. One of the solutions for which data are available, is the reduction of noise using a bubble curtain. For a generic cargo vessel travelling at 14 knots the reduction was estimated to be 3-6 dB, depending on the frequency range. The impact of such a system on fuel efficiency is estimated to be an increase in power demand by roughly 1-2% (AQUO Consortium, 2015).

3.5.3 Applicability

Adjustments or the application of these technologies can be made to existing ships (wake improvement devices, bubble curtains and applying noise isolation between the engine and hull) or new ships (optimising the foundation of the engine, bubble curtain technology) (Keizer, 2017, pers. comm., AQUO Consortium, 2012).

3.5.4 Costs/benefits

The impact of a bubble curtain system on fuel efficiency was estimated to be an increase in power demand by roughly 1-2% (AQUO Consortium, 2015). Other data on costs could not be obtained during the preparation of this report and requires further study.

3.6 Slower cruising speed

3.6.1 Description

The easiest way to reduce underwater noise is adhering to a slower cruising speed; by using a slower speed, the propeller will turn slower and cause less cavitation.

3.6.2 Effects

Lowering the speed reduces background noise, the amount of which depends on the cruising speed, type of propeller, etc. It also reduces fuel consumption but increases the time to travel from one harbour to another and in this way the delivery time for goods, which might have a negative effect on their value.

3.6.3 Applicability

This solution can be applied voluntary or by law or a combination of these two. In some regions of the world, this measure is being applied to protect sensitive areas, such as in Vancouver, Canada.

3.6.4 Costs/benefits

Potentially longer travelling times may increase the transport costs of goods. The additional costs depend on the extent of the measure applied (and as such cannot be quantified).

In Vancouver's Fraser Port EcoAction program (see 4.7.1), ships are eligible to pay lower port fees when noise reduction measures are applied (see the description below). This could potentially (partially) compensate for the costs of longer travelling times.

3.7 Economic instruments

3.7.1 Description

Economic instruments could be applied to stimulate ship owners to apply and install noise mitigation technologies and/or operational measures. In this section, economic instruments will be described that are aimed at rewarding ships which have mitigation measures in place to reduce continuous underwater noise.

Since 2007, ship operators in the port of Vancouver are eligible to pay lower port fees for ships that have implemented voluntary environmental measures and practices. The port fee is based on the gross registered tonne (GRT) and the ship's environmental category (the categorisation can only be done by an accredited certification agency). By meeting voluntary best practices, ships may obtain up to 47% off the basic port fee (Port of Vancouver, 2017).

On January 1, 2017, the port authority added new incentive criteria to the EcoAction program to include port fee discounts for quieter ships. The new criteria include three levels of quiet-vessel ship classifications, and three propeller technologies that reduce underwater noise. The port authority also recommends using specific technical measures that decrease cavitation and/or improve water flow around the ship's propeller (Port of Vancouver, 2017).

Currently, the EcoAction program is the only programme worldwide where the application of mitigation measures to reduce continuous underwater noise are a key indicator for reduced port fees. Other programmes where port fees are partially based on the environmental impact of ships are also in place throughout the world. Examples of such other programmes are:

- The Clean Shipping Index[2] (CSI). CSI is an independent labelling system of the environmental performance of ships and shipping companies. A key point is that this labelling system is aimed at rewarding ship-owners with clean ships a competitive advantage in the market. For example, from 2018 onwards, the Swedish Maritime Administration intends to give a significant tax reduction for well-performing vessels according to the Clean Shipping Index (Clean Shipping Index, 2018). Underwater noise is currently not one of the indicators but could in theory be incorporated in this scheme.
- The Green Award,[3] is a labelling scheme that rewards ships that are extra clean and extra safe. These ships receive a considerable reduction on port fees at ports in Belgium, Canada, Latvia, Lithuania, the Netherlands, Oman, New Zealand, Portugal and South Africa. This scheme mentions underwater noise as part of an elaborate system of parameters, but is not a key indicator such as in the case of Vancouver.
- The Environmental Ship Index[4] (ESI) is a labelling scheme that identifies seagoing ships that perform better in reducing air emissions than required by the current emission standards of the International Maritime Organization. The ESI evaluates the amount of nitrogen oxide (NOx) and sulphur oxide (SOx) that is emitted by a ship; it includes a reporting scheme on the greenhouse gas emission of the ship. The index is intended to be used by ports to reward ships when they participate in the ESI. In the Netherlands, both the Ports of Rotterdam and Amsterdam use this index to reward cleaner ships with lower port fees. Although the ESI only accounts for emissions to air (CO_2, SOx, NOx and PM), adding underwater noise to such a scheme could potentially be an interesting option to assess with the stakeholders involved.

3.7.2 Effects

The effects depend on the mitigation measures taken (see the paragraphs before).

[2] https://cleanshippingindex.com/
[3] www.greenaward.org/greenaward
[4] www.environmentalshipindex.org/Public/Home

3.7.3 Applicability

Programmes such as the EcoAction program, Green Award or the Clean Shipping Index are examples of programmes that are either currently adopted by Dutch ports and ship owners or could potentially be adopted in the future (possibly in an adjusted way) and in this way provide an incentive to take voluntary measures to mitigate the effects of continuous underwater noise.

3.7.4 Costs/benefits

For this report, specific data on costs and benefits of these programmes could not be obtained and requires further study.

3.8 Costs and benefits to the Netherlands

By interviewing several key stakeholders in the Netherlands, we have examined what the potential costs and benefits would be for the Netherlands, if stricter legislation and regulations would be in place to reduce continuous underwater noise from shipping. One of the focus points in the interviews was the question who would bear the costs and who would benefit from such legislation and regulations, either if applied only in the Netherlands or on an international (including regional) level.

3.8.1 Who would bear the costs

All people interviewed for this chapter share the view that (most) ship owners would most likely bear the costs of additional measures if current vessels need to be retrofitted and that it would be difficult to levy these costs to their customers due to competitive reasons. Currently there is (still) overcapacity in the world fleet, with the result that the freight tariffs are low and competition is strong. As a result of this, shipping companies hardly have any reserves to invest in new technology unless this is mandatory (such as ballast water treatment systems or air emission reduction technology). Therefore, noise mitigation technologies will likely only be applied if mandatory, not on a voluntary basis in the current situation of overcapacity.

If stricter or voluntary norms are only applied in Dutch seaports, these would be applicable to all visiting ships, regardless of their flag. To create a level playing field for seaports in terms of competitiveness, it would be better to cooperate with other ports in the North Sea and applying the same rules or regulations, in particular in cooperation with Belgian and German ports. In such a system, companies that take an effort in reducing underwater noise would be rewarded and the level playing field would not be distorted. In that sense the relative costs will not increase for shipping companies (Van de Minkelis, 2017, pers. comm.).

It should be noted that modifications and adjustments to ship design to reduce continuous underwater noise could be the same type of adjustments that can be applied to improve energy efficiency. For example, improvements in the design of propellers could improve energy efficiency as well as result in a reduction of noise caused by cavitation. In this way, a retrofit or upgrade of the propulsion system may also bring savings in fuel costs (Bosschers, 2017, pers. comm.).

3.8.2 Who would benefit

Traditionally, the Dutch maritime cluster is a strong sector, with a total turnover of €6.9bn for suppliers and yards collectively and a total workforce of 28,000 FTEs in 2017 (Netherlands Maritime Technology, 2018). The Dutch maritime cluster covers a broad spectrum of disciplines from education (several universities have maritime technology programmes), R&D institutes such as MARIN and TNO, ship designers, shipyards (both newbuilding and repair/maintenance) and suppliers of equipment. The focus point of this cluster is a strong trade association called Netherlands Maritime Technology.[5]

[5] https://maritimetechnology.nl/en/

Within the Dutch maritime and offshore sector, a considerable amount of expertise is present about the production of continuous noise and the effects of this (i.e. at MARIN, TNO, the ministry of Defence and some ship designers and builders). Based on interviews with key experts from the industry (see Appendix 1), the type of companies that could potentially benefit from stronger noise regulations have been identified as follows:

- Design and construction of noise mitigation technologies related to ship engines and ship propellers (e.g. Wärtsilä/Lips, Pon Power/Caterpillar)
- Adjustments to ships and the building of new ships at shipyards (e.g. Damen, Bodewes, VEKA)
- Engineering and research firms with expertise on underwater noise (e.g. Royal HaskoningDHV, Conoship)
- Research institutes with expertise on underwater noise and governance (e.g. TNO, MARIN, TU Delft, WUR, Deltares).

3.9 Discussion

In this chapter, we examined several noise mitigation technologies and economic instruments that could potentially be applied to reduce continuous underwater noise. These are mentioned in the table below:

Type of measure	Description	Effects	Applicability	Costs
Cavitation reducing technologies	Cavitation is the main cause of continuous underwater noise by shipping. The main solutions to reduce the noise generated by cavitation are improving the inflow to the propeller by wake optimisation or by modifying the propeller geometry: a larger, slow revolving, propeller produces less underwater noise than smaller propellers. Another technology that produces less cavitation is pod propulsion.	All of these solutions reduce underwater noise levels, although the amount varies, depending on the type of solution. Some of these solutions also have an effect on energy efficiency, where they reduce the amount of fuel needed for propulsion.	Some of the solutions entail fundamental changes to the ship and can only be implemented when building new ships (e.g. installing pod propulsion). Other adjustments can only be done when the ship is dry-docked every couple of years (e.g. installing a new propeller). In terms of its suitability at sea, changing the configuration of the propeller might be suitable in some situations, but not all (e.g. larger blades might stick out underneath the hull, making them more prone to the risk of damage due to contact with the seabed or sea-ice).	For this report, it has not been possible to obtain sufficient data on the costs of these technologies. It is known though, that modifications and adjustments to ship's propeller might result in an improvement in energy efficiency and thus savings in fuel costs.
2. Bubble curtains and engine noise insulation	*Bubble curtain technology* could be applied to reduce drag by injecting air bubbles into the cavitation. A relatively simple adjustment to the ship is formed by *wake improvement devices* such as spoilers or fins. Another option could be to *improve the maintenance of the*	The effects of these solutions vary, depending on the type of solution. One of the solutions for which data on the effects are available, is the reduction of noise using a bubble curtain. For a generic cargo vessel travelling at 14 knots the reduction was estimated to be 3-6 dB, depending on the frequency range. The impact of such a system	Adjustments or the application of these technologies can be made to existing ships (wake improvement devices, bubble curtains and applying noise isolation between the engine and hull) or new ships (optimising the foundation of the engine, bubble curtain technology).	The impact of a bubble curtain system on fuel efficiency is estimated to be an increase in power demand by roughly 1 - 2. Other data on costs could not be obtained during the preparation of this report and requires further study. Next to the costs involved, applying these technologies

Type of measure	Description	Effects	Applicability	Costs
	propeller and/or the hull to remove bio-fouling or repairing damages. To reduce noise coming from the main engine, and travelling through the hull, options could be to *optimise the foundation of the main engine or apply noise insulation* between the engine and hull.	on fuel efficiency is estimated to be an increase in power demand by roughly 1-2%.		could also result in energy savings (for example by applying a larger propeller or wake improvement devices).
3. Slower cruising speed	The easiest way to reduce underwater noise is adhering to a slower cruising speed; by using a slower speed, the propeller will turn slower and cause less cavitation.	Lowering the speed reduces background noise, the amount of which depends on the cruising speed, type of propeller, etc. It also reduces fuel consumption but increases the time to travel from one harbour to another.	This solution can be applied voluntary or by law or a combination of these two. In some regions of the world, this measure is being applied to protect sensitive areas, such as in Vancouver, Canada.	Potentially longer travelling times may increase the transport costs of goods. The additional costs depend on the extent of the measure applied (and as such cannot be quantified). This could potentially (partially) compensate for the costs of longer travelling times.
4. Economic instruments	In the Canadian EcoAction program, ship operators in the port of Vancouver are eligible to pay lower port fees for quieter ships. Next to the EcoAction program, other programmes are also in place where port fees are partially based on the environmental impact of ships; these do not specifically address underwater noise. Examples of such other programmes are the Clean Shipping Index (CSI), the Green Award and the Environmental Ship Index (ESI).	The effects depend on the mitigation measures taken.	Programmes such as the EcoAction program, Green Award or the Clean Shipping Index are examples of programmes that are either currently adopted by Dutch ports and ship owners or could potentially be adopted in the future (possibly in an adjusted way) and in this way provide an incentive to take voluntary measures to mitigate the effects of continuous underwater noise.	For this report, specific data on costs and benefits of these programmes could not be obtained and requires further study.

We also examined the potential costs and benefits to different stakeholder groups in the Netherlands. Based on the options, costs and benefits examined in this chapter, the following conclusions can be drawn:

- Especially during the last couple of years, the topic of continuous underwater noise has attracted the attention of governments, NGOs, regulators and standards bodies. As more knowledge is becoming available on its effects and potential solutions, the first steps are taken to look for possible measures and regulations. For example, within the Marine Strategy Framework Directive, one of the descriptors of Good Environmental Status is continuous noise. IMO has also started to look into this topic and has developed non-mandatory guidelines in 2014 (IMO, 2014).

- Based on the assessment carried out for this study, the main conclusion is that if extra regulation and/or a reward system (e.g. the Canadian EcoAction program) for voluntary measures would be in place to reduce continuous underwater noise caused by shipping, this will likely result in extra costs for certain shipping companies that have not (or are not willing to) install and apply mitigation measures. Other shipping companies that do implement measures may benefit from such measures (e.g. having lower port fees or creating a new customer base that support such initiatives). Some of these measures, such as cavitation reducing measures, may have originally been taken for fuel efficiency reasons, but the additional effect may be that underwater noise will be reduced.
- The EcoAction program shows that schemes aimed at rewarding voluntary action could work in practice to reduce underwater noise in certain geographical areas. In the Netherlands, the Green Award and the Clean Shipping Index are examples of programmes that are currently adopted by Dutch ports to reward more sustainable ships by lowering port fees. Adding underwater noise to such programmes (in a similar fashion as the EcoAction program) could potentially provide an additional incentive for ship owners to take voluntary measures to reduce continuous underwater noise.
- If applying stricter (voluntary or legislative) norms, it would be better to cooperate with other ports in the North Sea, in particular with Belgian and German ports. In such a system, companies that take an effort in reducing underwater noise would be rewarded and the level playing field of large North Sea ports would not be distorted.
- Having stricter regulations or more voluntary measures in place could create extra opportunities for the Dutch maritime sector, more specifically companies and research institutes that have the expertise, skills and R&D capacity to provide the products and services needed to make such a transition work. Several Dutch companies and research institutes have the expertise, skills and R&D capacity to provide the products and services needed to make a transition to reduced underwater noise by shipping.
- The interviews with stakeholders show that there is a wish and opportunity to join forces and look into the possibilities of developing a common strategy by all stakeholders involved (e.g. research agenda, policy initiatives, collaboration projects, etc.).

4 Applying the MyBeach concept along the entire Dutch coast

4.1 Introduction

One of the measures to reduce litter that is currently listed in the Dutch Programme of Measures for the Marine Strategy Framework Directive is the MyBeach concept. The aim of the MyBeach concept is to create a change in the behaviour and attitude of beach visitors in relation to litter, which should result in cleaner beaches and less marine litter in the Dutch part of the North Sea (EEZ). The MyBeach concept is currently operational at seven locations, while four others are in the planning stages (Nederland Schoon, 2018). It is currently not planned to implement the concept along the entire Dutch coast. In this chapter, we will further examine the costs and benefits of hypothetically extending the MyBeach concept along the entire Dutch coast.

4.2 Policy context

Beach litter monitoring results show that, during 2010-2015, there has been a significant decrease in both the total amount of beach litter items along the Dutch coast and of the main type of litter items commonly encountered on beaches. The results of the 2011-2016 period are similar (on average 364 items for every 100m of beach). According to the Dutch government, these results show that the measures in place (both in the Netherlands and abroad) to reduce beach litter seem to have effect (Ministerie van Infrastructuur en Waterstaat, 2018).

Most of the measures currently taken are part of the Green Deal Clean Beaches ('Schone Stranden'). The Green Deal Clean Beaches covenant was signed in 2014 by 33 parties. Next to the government, 19 coastal municipalities, the signatories also include a range of companies, volunteers, interest groups and civil society organisations (Ministerie van Infrastructuur en Milieu, 2014). By supporting the stakeholder process within the context of the Green Deal, the national government aims to include coastal municipalities and pavilion managers more and more in its policy to reduce litter, up until the point that they can pass the baton.

The aim of the Green Deal Clean Beaches is a substantial reduction in the amount of waste left on the beach by visitors by 2020. The Green Deal is also aimed at improving coordination and collaboration between these actors, preventing duplication of work, and enabling the Green Deal partners to learn from each other's experiences. The Green Deal for Clean Beaches has three objectives (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs, 2015):

1. Permanently cleaner beaches: Less litter should be found on the Dutch North Sea beaches by 2020.
2. Strong cooperation and coordination between parties: By 2020 all Dutch coastal municipalities should be united in the Green Deal for Clean Beaches. The number of participating beach operators, NGOs and other companies and organisations should increase annually between 2015 and 2020.
3. Proper attitude and behaviour of beach visitors: By 2020 beach visitors should leave less litter behind on the Dutch North Sea beaches.

To achieve these objectives, measures are signed and agreed upon by the signatories involved in cleaning up the Dutch part of the North Sea beaches and keeping them clean. One of the measures agreed upon by the actors who signed the Green Deal Clean Beaches is the MyBeach concept (Ministerie van Infrastructuur en Milieu, 2014). This concept is based around the idea that at designated MyBeach areas, visitors collect and dispose their own litter and do the same for any litter washed up on the beach. In addition to the measures already taken by the signatories, new specific actions have been agreed upon, in which these partners make an additional contribution to clean beaches (Ministerie van Infrastructuur en Milieu, 2014). Setting up MyBeach locations should therefore be seen in the broader context of making beaches cleaner and reducing the amount of litter at sea.

4.3 Current environmental status (MSFD)

The overall Good Environmental Status for litter (D10) is described as: The amount of litter at sea decreases over time. D10 is subdivided into several subcategories, of which beach litter is one (D10C1). It has been concluded that the overall status is not yet met but might be in 2020. The target set for beach litter (D10C1) is met however: monitoring efforts have shown a significant decrease in the trends of the most common litter categories (which contribute to 80% of the total amount of litter found on an average 100 metre stretch of beach). The ambition and aim of the Dutch government in the longer term is to reduce beach litter even more and work towards quantitative *regional* targets for beach litter (i.e. a 30% reduction) (Ministerie van Infrastructuur en Waterstaat, 2018).

4.4 Description of the MyBeach concept

The MyBeach concept is based around the idea that at designated MyBeach areas, visitors are aware that while on that stretch of beach they are not only required to collect and dispose their own litter but they have to do the same for any litter washed up on the beach. The aim is to create a change in the behaviour and attitude of beach visitors of a MyBeach location in relation to litter (where in some locations, visitors tend to leave or drop litter on the beach instead of into waste bins). If adopted along the entire Dutch coast, the MyBeach concept could act as a concept that results in a collective behaviour change, cleaner beaches and less marine litter (Nederland Schoon, 2018).

Figure 4.1 *Wooden letters to mark the MyBeach location*
Source: Nederland Schoon (2018).

The MyBeach project was initiated in 2011 by the North Sea Foundation, with support by the organisation Nederland Schoon, coastal municipalities and owners of beach pavilions. MyBeaches are spread over different municipalities along the entire coast (from Zeeland to the Wadden Islands). Currently, seven MyBeaches are fully operational, while four others are planned to be operational soon (Nederland Schoon, 2018).

The main reason and condition for pavilion managers to participate in MyBeach is that they are intrinsically motivated to take action to create cleaner beaches around their properties. To achieve this goal, the coastal municipalities and the entrepreneurs have coordinated their cleaning actions and made various agreements on who is responsible for what (part of the beach) and who will take which kind of action. In order to reduce the amount of litter on the beach, the most important thing is to bring about behavioural change among the visitors. In addition, pavilion owners can change their business processes and way of working. The actions taken to achieve this goal include (Nederland Schoon, 2018):

- Installation of the so-called 'bag pole' and associated beach waste bags. This is an innovation that is still being experimented with, both with respect to their use and their design (see Figure 4.2). The paper waste bags can be used to store the waste during a beach visit. The trash can be discarded when leaving the beach. Pavilion managers can also hand out the bags to people that buy something at their pavilion. It should be noted though that the bags do not work well combined with waste separation, since all trash is discarded in just one bag. So in this concept, getting rid of beach litter altogether has a higher priority than waste separation.

Figure 4.2 *An example of a so-called bag pole on a MyBeach location*
Source: Nederland Schoon (2018).

- Some beach pavilions use a checklist for staff regarding litter. For example, by walking on the beach in the morning before opening the pavilion and in the evening after closing time. They make an inventory of how clean the beach is and clean up the litter if necessary.
- Customised service may also help to avoid unnecessary waste. For example by asking the basic question whether the consumer wants milk or sugar when he orders coffee or tea. In addition, plastic bottles of water could be replaced by a glass bottle with drinkable tap water and cookies can be packed in a sealed cookie jar instead of separate packaging for every single cookie.
- In some places, sturdy plastic cups are used to replace glassware in order to reduce the risk of glass fragments.
- Garbage bins are positioned in strategic places (e.g. at the parking lot, at the entrance to the beach).
- Extra waste bins are installed at events and other activities with larger number of visitors.
- Effective and clear public information is provided. For example, a slogan on clean beaches on the clothing of staff, on windbreaks, on beach beds, et cetera. Or on a sign (A4 size) above the waste bins, even though one can argue that trash bins in strategic places may do a better job than yet another sign with lots of information on it (as it can even be seen as visual pollution).
- Beach pavilion managers keep the beach clean (as agreed in a lease agreement with the municipality). In that case, cleaning costs of the beach surrounding the pavilion are the responsibility of the pavilion manager. This is already practice in Zandvoort, where all pavilion managers (about 35) have agreed in the lease agreement with the municipality that they will keep the beach clean up to 10 meters from

the flood line. All parts of the free beach (not under the responsibility of a pavilion holder and the strip of 10 meters from the flood line) are the responsibility of the municipality; that contract has been put out to tender and is being carried out by a company.

The challenge is to push this further after 2020: in the end, in order to reduce the amount of litter on the entire Dutch beach, the concept should be implemented widely by municipalities and pavilions all along the coast of the Netherlands. Obviously, this can only be achieved gradually. At first, coastal municipalities and pavilion 'frontrunners', supported by the national government, experiment with the MyBeach concept to find out what measures are effective to reduce litter on the beach. Keep in mind that the impact of a package of measures should be assessed, rather than the effects of an individual measure.

Monitoring can play an important role in determining what the effect of these measures is. In 2017, the first ever dedicated monitoring took place specifically focused on litter found on tourist beaches. As part of the Green Deal Clean Beaches, a fill-in form had been drawn up for this, called 'Field form for counting litter on tourist beaches'. On the form, one can indicate for every type of item how many pieces have been found on the beach. This list includes commonly found items such as lighters, cotton swabs, ice sticks, and pieces of glass. Strand Nederland monitors tourist beaches twice a year based on this form. The pavilion managers are not obliged to monitor a certain number of times per year, but usually do this a few times a year. The monitoring data are not available yet, but will give an impression of what is left behind by tourists and recreationists on the beach. This might also show the differences or similarities between MyBeaches and other tourist beaches.

4.5 Costs of measures

In this section, the costs of both conventional beach cleaning and the MyBeach concept will be described. By applying the MyBeach concept, the costs of conventional beach cleaning could potentially be reduced. For the purpose of the analysis in this report, we have tried to collect as much data on costs as possible to be able to calculate a potential reduction in conventional cleaning costs when applying the MyBeach concept. However, it should be noted that the type and quality of data available are not sufficient to be able to make such a calculation. The information provided below on both the costs of the MyBeach concept and conventional beach cleaning can therefore not be compared but does provide insight into the costs involved.

Costs of the MyBeach concept

Information on the costs of the MyBeach concept is available but not complete. We have found costs for items such as poles, boxes with waste bags, and waste bins. For the other measures, such as avoiding unnecessary trash and more information/promotion clean beaches, the costs could not be quantified and will be described instead. These costs are the costs that are involved with taking these measures (see Table 4.1):

Table 4.1 *Measures and costs regarding the MyBeach concept*

Measures	Costs
Use paper beach waste bags and so-called 'bag pole'	€227 for the 'bag pole', €20 for a box with 250 waste bags
Replace glasses with hard plastic cups (Dutch Cups)	€0.62 to €0.89 per cup (25 cl), quantity discount applies. Prices based on model Folk: https://dutchcups.nl/product/folk/
Avoid unnecessary trash	Low (slight adaptation of business practice)
Checklist employees for cleaning activities	Low (slight adaptation of business practice)
Pavilion managers keep the beach clean (as agreed in the lease agreement with the municipality)	Moderate (cleaning costs beach are the responsibility of the pavilion manager)
Use extra waste bins (at events and other activities)	€80 per waste bin
More information on and promotion of clean beaches	Low (promotion material and marking stuff)

Costs of beach cleaning activities
Ecorys (2012) interviewed 16 out of 28 coastal municipalities on their beach cleaning activities. According to the report, the 'selected municipalities are representative, so that the whole variety of local situations is counted, and not biased by one particular situation.' There are also major differences between coastal municipalities in the way they deal with marine litter; which stakeholders are involved and who bears responsibility for the adoption of waste facilities and the removal of beach litter. Out of the 14 coastal municipalities that have provided information, all but one have hired a third party (such as a contractor or the waste processing industry) for either cleaning the beach or processing the waste. In two municipalities the beaches are cleaned manually; in all other cases a beach cleaner is used, sometimes complemented with manual beach cleaning (Ecorys, 2012).

Many of the municipalities and other organisations have required to keep the cost information confidential. All cost figures provided in the Ecorys (2012) report have been anonymised and aggregated so that the information cannot be traced back to a single municipality. In total, 14 coastal municipalities have provided an indication of the total costs. The costs amount to approximately €2.5m on an annual basis. This includes all costs incurred on the spot, including the amount that may be spent by pavilion holders or other beach operators. On average, beach cleaning costs account for the largest part of the costs of beach waste, approximately 69%. The costs of waste container management and the disposal costs amount to approximately 21% and 10% respectively of the total costs (Ecorys, 2012).

Due to the fact that a similar analysis as the one carried out by Ecorys has not taken place since 2012, it is not possible to compare the costs of cleaning MyBeach beaches with other beaches.

4.6 Benefits of measures

The first and foremost benefit of the MyBeach concept is that it will likely result in a behaviour change, where beaches will be cleaner and that less litter will end up at sea. This might also result in lower costs to municipalities to clean beaches. For this study, due to a lack of data, it has not been possible to calculate this amount.

Another benefit may be that clean beaches are valued more by visitors than dirty beaches. Brouwer et al. (2017) interviewed visitors of beaches in The Hague (Scheveningen and Kijkduin) on their perspective on beach littering and cleansing. About 42% of the visitors considered beach littering annoying and 30% very annoying. Moreover, 66% of all interviewed beach visitors indicated that they would stop visiting a dirty beach due to littering. They were also asked if they were willing to volunteer in cleaning actions for the beach where they were interviewed, and if so, for how many hours per year. On average, the visitors were willing to volunteer at most 3.4 hours per visitor per year with a 72% refusal rate (Brouwer et al., 2017).

4.7 Discussion

A measure that is taken in the Netherlands to reduce litter on the beach is the MyBeach concept. The aim of the this concept is to create a change in the behaviour and attitude of beach visitors in relation to litter by requiring them to collect and dispose their own litter, and do the same for any litter washed up on the beach at designated MyBeach areas. Currently, seven MyBeaches are fully operational, while four others are planned to be operational soon. As these locations are 'frontrunners' in adopting the MyBeach concept, there is still room to experiment what measures are effective. If the concept would be adopted along the entire Dutch coast at a later stage, MyBeach could act as a concept that results in a collective behaviour change, cleaner beaches and less marine litter.

For the purpose of the analysis in this report, we collected as much data on beach cleaning costs as possible to be able to calculate a potential reduction in conventional cleaning costs when applying the MyBeach concept. However, the type and quality of data available are not sufficient to make such a calculation. In particular, monitoring data on tourist beaches with and without the MyBeach concept is lacking, as is detailed data on the costs of conventionally cleaning the beach and the reduction in costs that presumably results from applying the MyBeach concept.

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Appendix 1 Consulted experts

Bosschers, Johan	MARIN
Deesker, Roel	Gemeente Zandvoort
Dekeling, René	Ministerie van Infrastructuur & Milieu
De Jong, Christ	TNO
Jung, Bob	IHC IQIP
Keizer, Tjakko	Damen
Kerkhofs, Stan	Rijkswaterstaat
Van de Minkelis, Niels	KVNR
Van der Stee, Stephan	Strand Nederland
Winkes, Jasper	Fistuca BV

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

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Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
The Netherlands
E communications.ssg@wur.nl
www.wur.eu/economic-research

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.