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**TNO report**

**TNO 2020 R11855**

# Reduction of emissions and underwater radiated noise for the Belgian shipping sector


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# 1 Introduction

Over 90% of the world's trade occurs via maritime transport. Air pollution, greenhouse gas (GHG) emissions and underwater radiated noise are unintended by-products of this international shipping. The maritime sector is aware of the need for energy efficiency and greenhouse gas reduction. In 2018, the International Maritime Organization (IMO) has adopted an Initial Strategy on reduction of GHG emissions from ships[1]. This confirms IMO's commitment to reducing GHG emissions from international shipping and, as a matter of urgency, to phasing them out as soon as possible in this century. With the 'Plan for Sustainable Shipping' (reproduced in Annex B to this report), the Belgian government wants to help shipowners towards a greener, $CO_2$-free and digital future for the sector. The plan is in line with the international objective of reducing carbon dioxide ($CO_2$) emissions from the shipping sector by at least half by 2050.

Besides GHG, IMO has a progressive reduction approach of nitrogen oxides ($NO_x$), sulphur oxides ($SO_x$) and particulate matter (PM) to prevent air pollution from ships[2]. To help protect maritime wildlife, IMO's work includes reduction of underwater noise from ships[3]. In 2014, IMO published nonmandatory guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life [IMO MEPC, 2014].

Ideally, measures taken to reduce GHG emissions would also reduce underwater noise, but the link between the two has not yet been clearly demonstrated. In this study, commissioned by the Dienst Marien Milieu (DMM) of the Belgian federal public service for Health, Food chain safety and Environment, we investigate the options for reducing GHG emissions as well as underwater noise, with a focus on the Belgian shipping fleet.

The following approach was chosen:
1 Create an overview of the characteristic ship types in the Belgian fleet, including cargo vessels, tankers, fishing boats, dredgers and offshore support vessels.
2 Provide a global analysis of the current underwater radiated noise and emissions ($CO_2$, $NO_x$, $SO_x$, PM) of these characteristic ship types.
3 Provide an overview of possible reduction measures for emissions and underwater radiated noise.
4 Analyse the potential co-benefits of measures for reducing underwater vessel noise for energy efficiency and GHG reduction.

As Part 2 of this study, TNO has investigated the potential for reducing air emissions as well as underwater noise with a so-called operational ‘slow steaming’ scenario for the North Sea region, in which the maximum speed of the ships is limited in order to save energy and reduce emissions, see [de Jong and Hulskotte, 2020].

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[1] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/GHG-Emissions.aspx
[2] www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx
[3] http://www.imo.org/en/MediaCentre/HotTopics/Pages/SustainableDevelopmentGoals.aspx#number14

# 2 Belgian shipping fleet

## 2.1 Introduction

As input for this study, the Dienst Marien Milieu (DMM) of the Belgian federal public service for Health, Food chain safety and Environment has provided a list of ships from Belgian owners, with their main parameters. This list has been anonymized and grouped in terms of characteristic ship types representing the Belgian fleet. This chapter provides an overview of the information. The GHG emissions and underwater noise radiation for the various ship types are analysed in the next chapter.

## 2.2 Belgian merchant shipping fleet

The information provided by DMM was obtained from a database search for ships of Belgian owners by Clarkson Research Services Limited (2020). The database parameters provided are summarized in Table A.1 (Appendix A).

The database search resulted in a list of 452 ships. The main characteristics (such as tonnage, length and design speed) per ship type are summarized in Table A.2 (Appendix A).

In gross tonnage (GT), Belgium has the 15th largest fleet worldwide, but in number of ships the size of the Belgian fleet is limited. The 4$^{th}$ IMO GHG study estimates the total world fleet at 119.626 vessels in 2018 [CE Delft e.a., 2020].

Figure 1 shows the numbers of ships in the Belgian fleet per ship type. The largest groups are the dredgers, the crude oil tankers and the bulk carriers.

Figure 2 shows the size distribution (expressed in gross tonnage; GT) of the ships in the main classes. This illustrates that the largest ships in the Belgian fleet are mainly tankers.

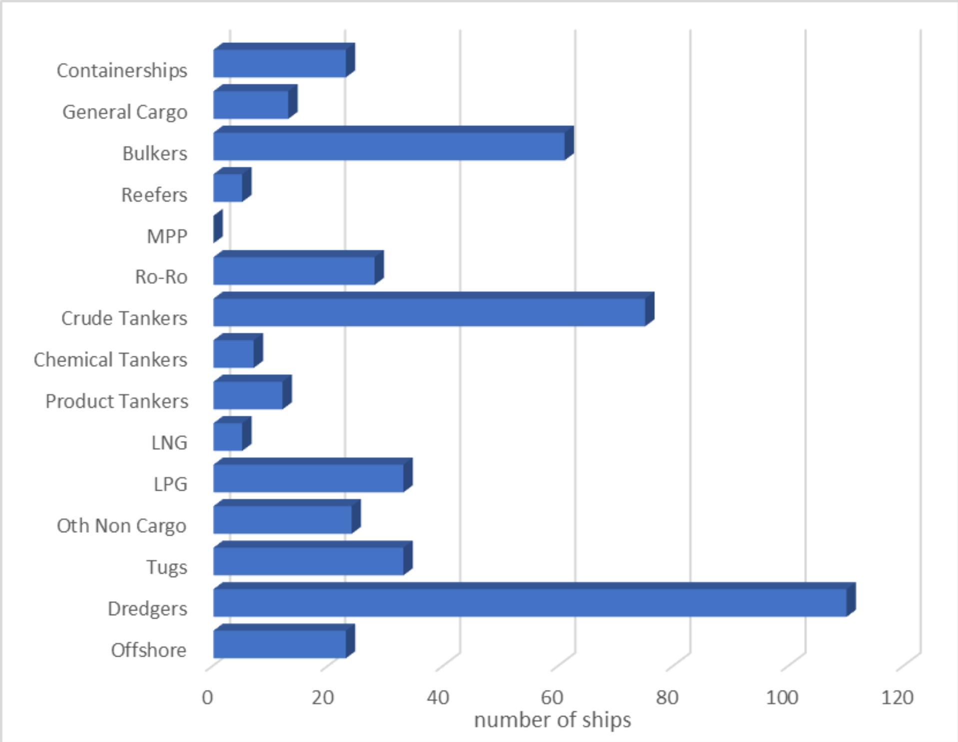



Figure 1 Number of ships of Belgian owners per ship type.

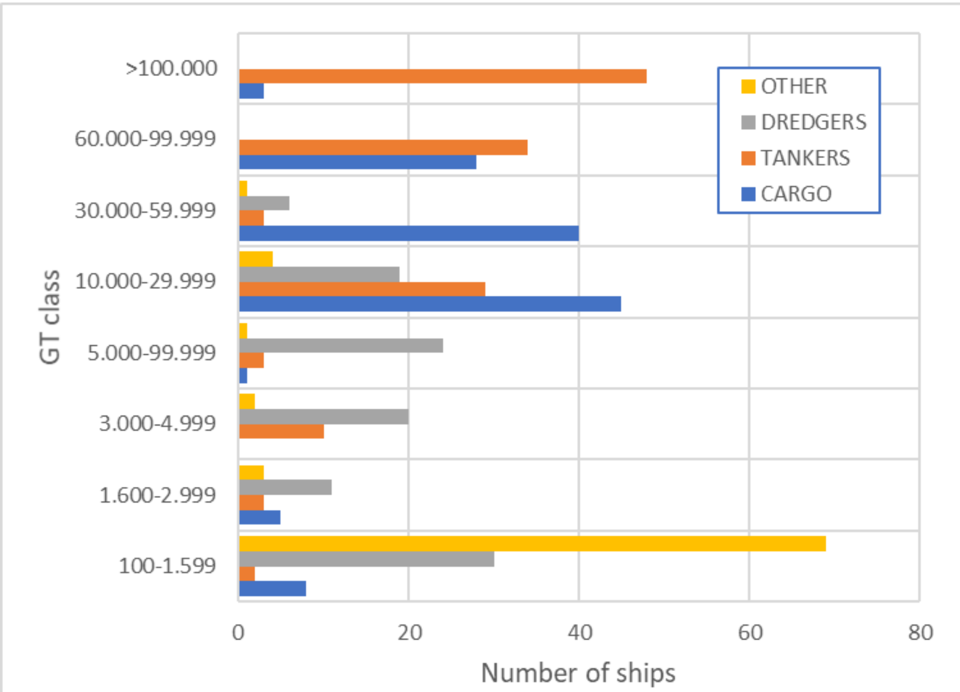



Figure 2 Number of ships of Belgian owners per size class (gross tonnage GT) and per class of ship types (CARGO = Containerships, General Cargo, Bulkers, Reefers, MPP and Ro-Ro; TANKERS = Crude Tankers, Chemical Tankers, Product Tankers, LNG and LPG; OTHER = Oth Non Cargo, Tugs and Offshore Vessels).

# 3 Analysis of emissions and underwater radiated noise of the Belgian shipping fleet

## 3.1 Introduction

What are the typical contributions of the Belgian shipping fleet to emissions and underwater radiated noise? Which ship types have the greatest contribution? Is there a correlation between emissions of greenhouse gases and underwater radiated noise? These questions have been studied on the basis of the parameters that were obtained from the database search for ships of Belgian owners (see Chapter 2).

## 3.2 Emissions

In order to estimate the total emissions of the Belgian fleet, the following steps have been taken:
- Estimation of the total annual sailing hours and energy consumption for all vessels. When available, these data were provided for the individual vessels based on the EU Monitoring, Reporting and Verification database (THETIS-MRV). The data were verified and supplemented with the use of key figures from IMO (2015).
- Based on the energy consumption data and the data on the fuel type used for each vessel, the emissions of the fleet were calculated by applying emission factors derived from TNO (2019), Marin (2019) and JRC (2014). For the assessment, the tank-to-wake emissions (TTW, for shipping also referred to as tank-to-propeller or TTP) have been considered. This does not include emissions from the upstream fuel chain (well-to-tank or WTT). Furthermore, the fuel sulphur content can reasonably assumed to be 0.1%, so potentially, if the ships would use 0.5% sulphur fuel, the total amount of $SO_x$ emissions can be 5 times higher. At the same time, due to the sulphur related PM emissions, the total PM emissions can be about 40% higher.

Based on this analysis, the estimated annual Tank-to-Wake emissions for the Belgian fleet are:
- $CO_2$: 7819 thousand tonnes,
- $NO_x$: 200 thousand tonnes,
- PM: 4 thousand tonnes,
- $SO_x$: 5 thousand tonnes.

- The calculated emission levels per ship type are summarized in Table 1. In the second row the totals of each column are displayed. The number of ships and their share compared to the total fleet are given per ship type in the second and third column, respectively. The $CO_2$, $NO_x$, PM, and $SO_x$ emissions as a percentage of the total fleet are given per ship class in the last four columns. The three most polluting ship classes have been highlighted with bold font: Bulkers, Crude Tankers, and LPG ships.
- Crude Tankers is by far the most polluting group in all the four studied emissions, contributing 32.8% to 37.4% of the total emissions of the fleet, whereas the share of Crude Tankers to the total number of ships is only 16.6%. On an individual ship basis, an LPG ship has a similar footprint as a Crude

Tanker. Bulkers as a group contribute as much to pollutant emissions as the LPG group, but the number of Bulkers in the fleet is almost twice as high as LPG ships, meaning that an individual Bulker ship is contributing about half the amount of a LPG ship.
- On the note of individual ship emissions instead of the emissions of the entire group for a certain ship type, the most polluting ship in the fleet is an LNG ship. An individual LNG ship contributes about 1% to the total fleet emissions, about two times more than a Crude Tanker. Other heavy-polluters are the Containership (similar to a Crude Tanker), the Ro-Ro ship, and the Product Tanker.
- The individual $CO_2$ emission levels are plotted as a function of the gross tonnage in Figure 3.

Table 1 Estimated emissions ($CO_2$, $NO_x$, PM, and $SO_x$) per ship category of the Belgian fleet. The percentages indicate the contribution of the sum of all ships per ship type to the total emission by all ships examined (not all ships worldwide).

| | **nr** | | **Annual $CO_2$ contribution** | **Annual $NO_x$ contribution** | **Annual PM contribution** | **Annual $SO_x$ contribution** |
|---|---|---|---|---|---|---|
| **Type** | **452** | % of nr | % of total 7.8e6 tonnes | % of total 2.0e5 tonnes | % of total 4.5e3 tonnes | % of total 5.0e3 tonnes |
| Containerships | 23 | 5.1% | 10.5% | 11.3% | 11.1% | 10.5% |
| General Cargo | 13 | 2.9% | 0.9% | 0.8% | 0.8% | 0.9% |
| **Bulkers** | **61** | **13.5%** | **13.4%** | **14.0%** | **12.1%** | **13.4%** |
| Reefers | 5 | 1.1% | 0.3% | 0.4% | 0.5% | 0.3% |
| MPP | 0 | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Ro-Ro | 28 | 6.2% | 7.6% | 5.6% | 11.2% | 7.6% |
| **Crude Tankers** | **75** | **16.6%** | **35.4%** | **37.4%** | **32.8%** | **35.5%** |
| Chemical Tankers | 7 | 1.5% | 0.7% | 0.7% | 0.8% | 0.7% |
| Product Tankers | 12 | 2.7% | 3.5% | 3.0% | 5.1% | 3.4% |
| LNG | 5 | 1.1% | 4.8% | 5.4% | 5.4% | 4.9% |
| **LPG** | **33** | **7.3%** | **13.4%** | **14.1%** | **12.9%** | **13.4%** |
| Oth Non Cargo | 24 | 5.3% | 0.6% | 0.4% | 0.4% | 0.6% |
| Tugs | 33 | 7.3% | 1.2% | 0.8% | 0.9% | 1.2% |
| Dredgers | 110 | 24.3% | 6.7% | 5.2% | 5.1% | 6.6% |
| Offshore | 23 | 5.1% | 1.0% | 0.8% | 0.8% | 1.0% |

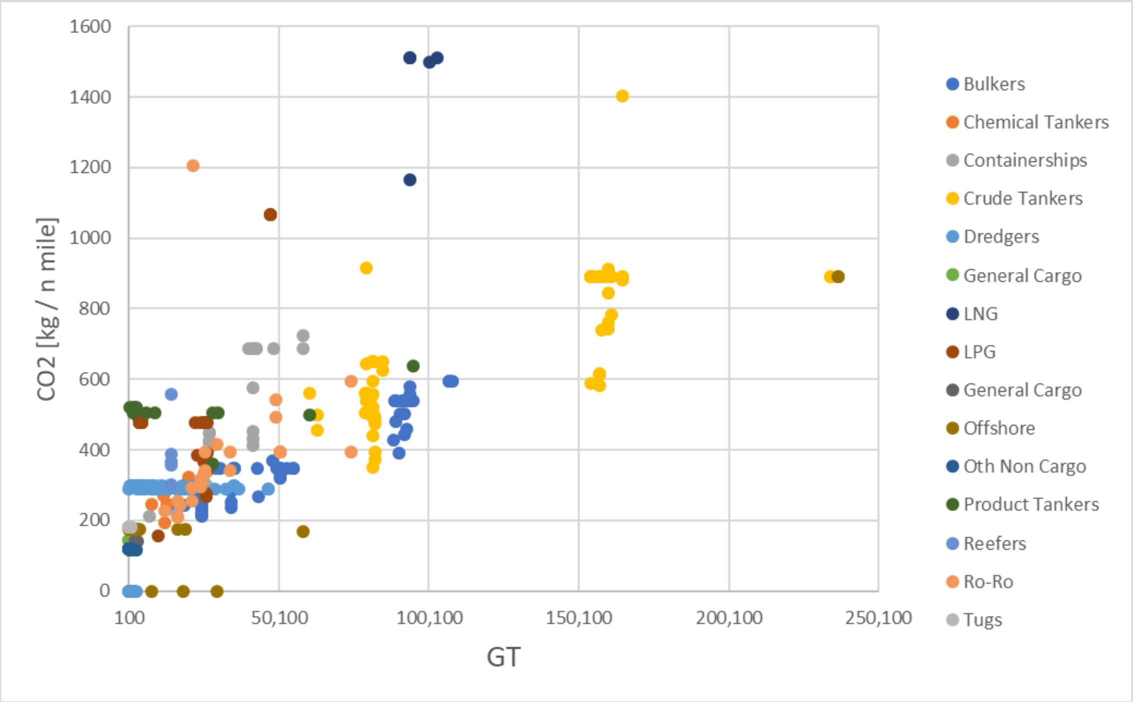



Figure 3 Estimated $CO_2$ emission per nautical mile, as a function of the gross tonnage (GT).

### 3.3 Underwater radiated noise

In the Interreg programme Jomopans[4], TNO and JASCO developed a trend model for quantifying ship noise source levels based on parameters available from AIS transmissions. The model is based on trends observed in the data base of ship source levels measured in the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) program [MacGillivray et al, 2019].

This JOMOPANS-ECHO model calculates the ship source level spectrum, associated with a 6 m source depth, as a function of frequency ($f$), ship speed over ground ($V$), ship length ($l$) and ship type (vessel class, $vc$), where $V_{vc}$ is a fitted reference speed per vessel class and $l_0 = 100$ m is a fixed reference length for all vessel classes:

$$L_S\,(f, V, L, vc) = L_{S0}(f, vc) + 60\log_{10}(V/V_{vc})\text{ dB} + 20\log_{10}(l/l_0)\text{ dB},$$

Using this model, the source level of the ships in the Belgian fleet (Chapter 2) has been calculated, assuming that the ships all sail at their design speed. The calculated source levels per ship type are summarized in Table 2. The individual unweighted broadband source levels are plotted as a function of the gross tonnage in Figure 4. The 'non propelled' dredgers and offshore platforms are ignored in this analysis. Note that these calculations provide a statistical estimation of the source levels per ship type and do not give a prediction of the radiated noise characteristics of individual vessels. The uncertainty in the source level prediction for individual ships is about 7 dB (the standard deviation of the difference between the model prediction and measurements of individual vessels in the ECHO database).

[4] https://northsearegion.eu/jomopans/

Table 2 Calculated source level (SL) associated with a 6 m source depth of the Belgian ship types when they sail at their design speed. The last column provides a tentative first estimation of the percentage contribution of the sum of all ships per ship type to the total underwater sound power radiated by all ships. This estimation of the instantaneous sound power is based on the unrealistic assumption of all ships of the fleet sailing at design speed and simultaneously.

| | **nr** | | | **SL [dB re 1 µPa-m]** | | **Sound power contribution** |
|---|---|---|---|---|---|---|
| **Type** | **452** | % of nr | min | avg | max | % of total |
| **Containerships** | **23** | **5%** | **178** | **189** | **195** | **10%** |
| General Cargo | 13 | 3% | 151 | 165 | 173 | 0.02% |
| **Bulkers** | **61** | **13%** | **177** | **187** | **191** | **11%** |
| Reefers | 5 | 1% | 186 | 188 | 188 | 1% |
| Ro-Ro | 28 | 6% | 177 | 183 | 191 | 3% |
| **Crude Tankers** | **75** | **17%** | **188** | **192** | **201** | **42%** |
| Chemical Tankers | 7 | 2% | 181 | 183 | 184 | 0.4% |
| Product Tankers | 12 | 3% | 166 | 178 | 188 | 1% |
| LNG | 5 | 1% | 196 | 196 | 196 | 7% |
| LPG | 33 | 7% | 176 | 184 | 188 | 4% |
| Oth Non Cargo | 24 | 5% | 171 | 180 | 191 | 3% |
| Tugs | 33 | 7% | 174 | 181 | 187 | 2% |
| **Dredgers** | **110** | **24%** | **161** | **182** | **199** | **16%** |
| Offshore | 23 | 5% | 159 | 175 | 187 | 1% |

Figure 4 illustrates that within the different ship types there is a rather strong correlation between ship size (GT) and source level, because both ship length and design speed are larger, on the average, for larger vessels.

The estimated source levels can be used to get a rough indication of the ship classes for which radiated sound reduction would be the most effective. The ‘sound power contribution’ in Table 2 gives the calculated contribution per ship class to the total radiated sound power when all ships would be sailing at the same time and at their design speed. Although this is an unrealistic scenario, it suggests that noise reduction would be most effective for crude oil tankers, bulkers, containerships and dredgers. Figure 5 illustrates that the big representation of larger size tankers in the Belgian fleet has potentially the largest contribution to underwater noise.

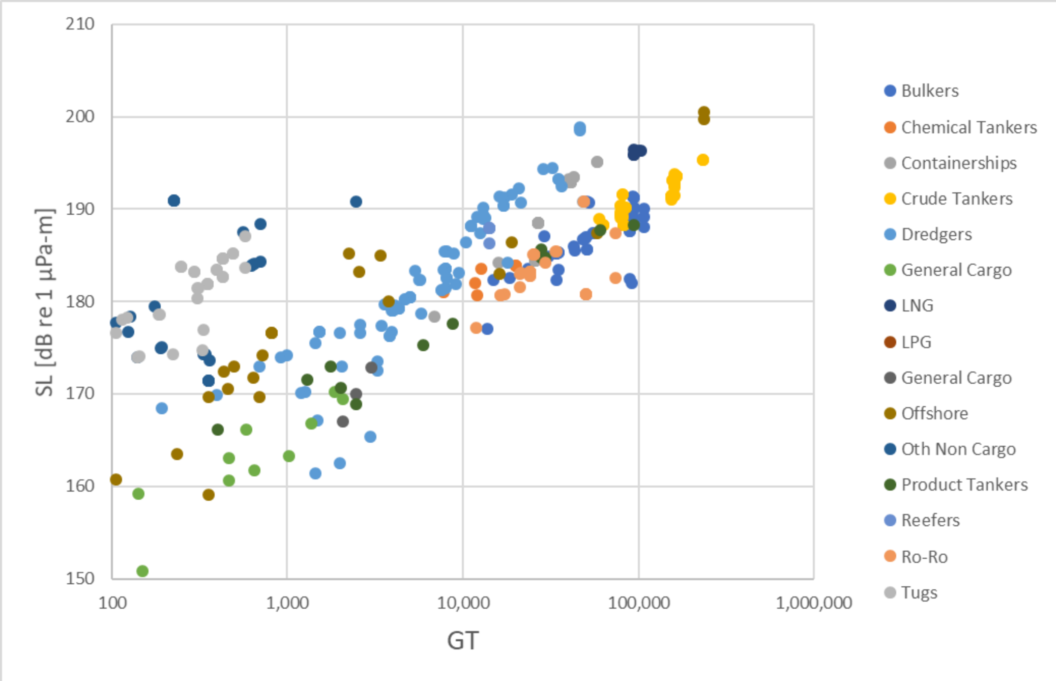



Figure 4 Calculated source level (SL), associated with a 6 m source depth, of the Belgian ships when they sail at their design speed, as a function of the gross tonnage (GT). The source level model depends on ship length rather than GT, but Length between particulars (Lpp) was not provided in the database search. Therefore length $L$ was estimated from GT based on the regression formula $L \approx (20 \times \mathrm{GT})^{0.4}$, see Appendix A.

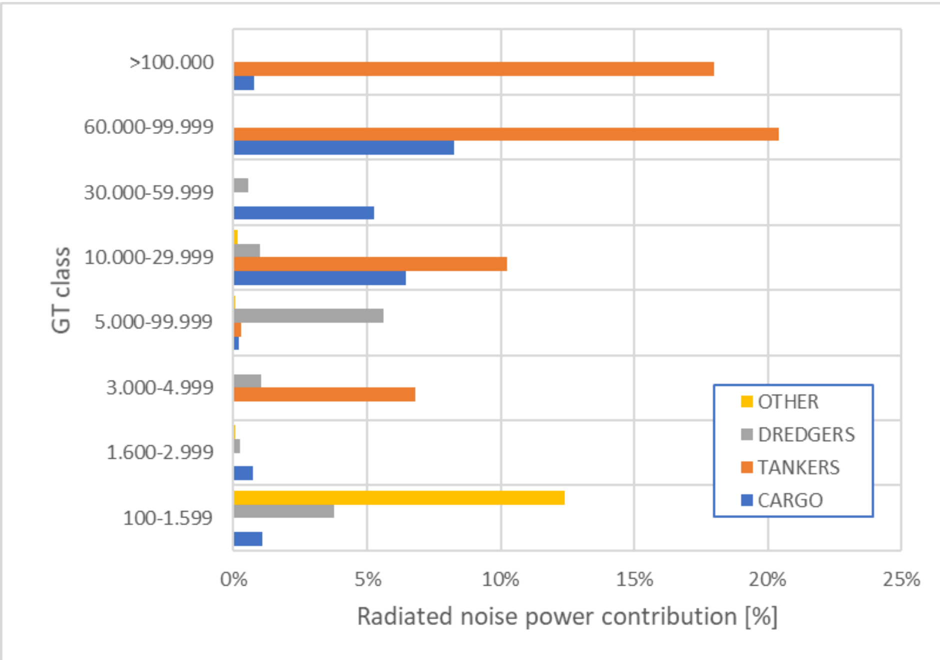



Figure 5 Calculated contribution to the total radiated sound power per size class (gross tonnage GT) and per overall class of ship types when all ships would be sailing at the same time and at their design speed. (Although this is an unrealistic scenario, it provides an indication of the ship classes that could potentially have the largest contribution). For this overview, the ship types have been grouped in classes Cargo (Containerships, General Cargo, Bulkers, Reefers and Ro-Ro), Tankers (Crude Tankers, Chemical Tankers, Product Tankers, LNG and LPG), Dredgers and Other (Oth Non Cargo, Tugs and Offshore).

Underwater sound maps can provide a more realistic insight into the contribution of the different ship types to the underwater soundscape at various locations. In part 2 of this study, North Sea sound maps will be produced for this purpose, based on actual ship traffic information, from Automatic Identification of Ships (AIS) and Vehicle Monitoring System data.

The above analysis of underwater radiated noise based on the simplified JOMOPANS-ECHO model is mainly useful for a statistical assessment of shipping noise in sea basins. The standard deviation of the distribution of measured source levels of individual ships around the model predictions is about 7 dB. Hence this model, which is based on a very limited set of parameters, is not suitable for the assessment of radiated noise from individual vessels, see Chapter 5.

# 4 Options for emission reduction

## 4.1 Regulations on emissions

### *4.1.1 Regulations on greenhouse gas emissions*

The main goal of the initial IMO greenhouse gas reduction strategy is to reduce greenhouse gas emissions (GHG) from shipping in 2050 by at least 50% compared to the 2008 emissions level (IMO 2018).

As part of the strategy, the following measures have been defined: further strengthening of energy efficiency design index (EEDI) for different ship vessel types and to improve the operational efficiency in two stages:

- By 2030: 40% $CO_2$ reduction per transport work, expressed in gram $CO_2$ per ton per nautical mile (ton.nm) compared to 2008;
- By 2050: 70% reduction per transport work, expressed in gram $CO_2$ per ton per nautical mile (ton.nm) compared to 2008. Reduction of 50% of the absolute GHG emissions compared to 2008.

Possible technical, operational and market-driven measures for reduction over the short, long and medium term still need to be defined and are currently under discussion.

The sections below summarize the most important policies which underpin the regulatory framework for the sustainability aspects of the maritime shipping sector. Particular focus is given to:

- Policies that have an impact on the energy efficiency of the ship and thus $CO_2$ emissions of vessels;
- Regulations on other types of emissions beyond $CO_2$;
- Fuel regulations.

### *4.1.2 Energy efficiency policies*

The *Energy Efficiency Design Index (EEDI)* is a mandatory IMO regulation for new vessels with keels laid down as of the 1$^{st}$ of January 2013. Ship types where EEDI is applicable account to 85% of the $CO_2$-emissions of the world fleet (IMO 2020). The EEDI for new ships aims to promote the use of more energy efficient (less polluting) equipment and engines, requiring a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different vessels in accordance with their ship type, size and sector within which they operate.

The *Ship Energy Efficiency Management Plan (SEEMP)* is an operational fleet management measure that establishes a mechanism to improve the energy efficiency of a ship in terms of cost-savings as well as environmental protection. The SEEMP became legally binding as of the 1st of January 2013 according to IMO regulation MEPC.203(62), for all active, operational vessels (IMO 2020).

Closely related to the SEEMP is the monitoring tool: *Energy Efficiency Operational Indicator (EEOI)*. The EEOI shall allow operators to measure the fuel efficiency of a ship in operation and to estimate the impacts of any changes in operation, e.g. improved voyage planning, or more frequent propeller cleaning, or the introduction of technical measures such as waste heat recovery systems or a new propeller.

The *Regulation for the monitoring, reporting and verification of carbon dioxide emissions from maritime transport (EU MRV)* requires vessels over 5,000 GT that are loading/ or unloading cargo and/or passengers at European ports to monitor and report their related $CO_2$ emissions. The first monitoring and monitoring reporting cycle has begun January 1st, 2018, with two data sets collected:

- Data on fuel consumption for all maritime voyages from, to and within the European Union is converted to $CO_2$-emissions (ton) using emission factors from the 2014 guidelines for calculating the EEDI (resolution MEPC.245(66)).
- Data on total transport work on these voyages (either cargo in tons or number of passengers).

The IMO has also set up a *Data Collection System (IMO DCS)* as part of the SEEMP. Aggregated data are collected on fuel consumption and are therefore less detailed than the MRV. The first reporting period began January 1st, 2019.

### *4.1.3 Regulations on other emissions*

Besides regulations focussing on $CO_2$-emissions there are policies focussing on air pollutant emissions. Concerning the emission of Nitrogen Oxides ($NO_x$), limits have been set for new build ships when operating in a nitrogen emission control area (NECA). The current regulatory level in a NECA is *Tier III* and applies to ships constructed after a specific date. Outside of the NECA, IMO Tier II is of application. The allowed $NO_x$ levels emissions in Tier III are about 80% less than that of Tier I (ships vessels built after January 2000). NECA has been set up in coastal waters around USA and Canada with effect as of January 1st, 2016 for new build vessels. As of January 1st, 2021, a NECA will apply to the North Sea and the Baltic Sea.

Fuel regulations: As of January 1st, 2020, the allowed $SO_x$ and PM limit outside of emission control areas will be reduced significantly. The worldwide fuel sulphur and PM limit will reduce from 3.5% m/m (mass by mass) to 0.5% m/m.

Another emission that is under discussion by IMO for possible future regulation is Black Carbon. Black Carbon is a subset of PM at the range of tens of nm particle size. These particles have been identified as distinctly hazardous for human health and creating significant atmospheric warming [REF: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/Black%20Carbon.pdf].

### *4.1.4 Fuel sustainability regulations*

European fuel regulations also shape the further development of the shipping sector towards alternative fuels with the most important regulations mentioned as follows.

The EU *Renewable Energy Directive II (RED II)* sets targets for the use of renewable energy until the year 2030 (DG MOVE 2019b). RED II has been adopted in 2018 and replaced the Renewable Energy Directive from 2009. RED II sets an overall EU target for Renewable Energy Sources consumption of 32% by 2030.

Furthermore, RED II defines a series of sustainability and GHG emission criteria that bioliquids used in transport must comply with, in order to be included in the overall target of 14% renewables.

Maritime, as well as aviation, is exempted from RED II, however, Member States can “opt in” the sectors to contribute to the target. The contribution of “non-food renewable fuels” supplied to these sectors will count 1.2 times their energy content (DG MOVE 2019). If waste feedstock (listed in Annex IX, A) are used, the 1.2 energy content will be counted twice leading to a 2.4 multiplier. This makes the application of biofuels in the maritime sector attractive for reaching the overall target.

The *Alternative Fuels Infrastructure Directive (AFID)* adopted by European parliament in 2014, required the development of national policy frameworks to address the development of alternative fuels in conjunction with their associated infrastructure development and accompanying the development of technical standards (DG MOVE 2019a). Furthermore, the directive required a minimum coverage for infrastructure of certain alternative fuels. As part of AFID, ports that have been identified as maritime core ports in the Trans-European Transport Network (TEN-T) (40 major ports in Europe, including Antwerp, Gent, Oostende and Zeebrugge) are required to be able to provide bunkering of LNG by the end of 2025. AFID does not refer to gradual uptake of any other alternative fuels within the maritime sector or indeed support any potential contenders to LNG when such actions should be required. Development of infrastructure for fuels (such as hydrogen, methanol, and ammonia), therefore needs to be addressed through new regulations.

## 4.2 Overview of emission reduction measures

Emission reduction can be achieved in numerous ways depending on which emission one wants to reduce, and which types of measures are technically and economically feasible. The breakdown of $CO_2$ emission sources from shipping is a useful approach to understand which factors affect the total $CO_2$ emission. These factors and their meaning are shown in the schematic in Figure 6. The green, red, orange, and grey blocks represents the carbon intensity of the energy carrier, the ship efficiency, operations and logistics, and product volume and characteristics, respectively. The figure shows $CO_2$-emissions as an example; however the formula is also applicable for other air pollutant emissions such as $NO_x$, $SO_x$

The other emissions, namely $NO_x$, $SO_x$, and PM, relate in one way or another to the same emission factors as shown in Figure 6, except for the carbon intensity of the energy carrier (which is obviously the only factor that directly relates to $CO_2$). In other words, for a given fuel and powertrain technology, the emissions of $NO_x$, $SO_x$, and PM will also scale with the ship efficiency, load factor, etc.

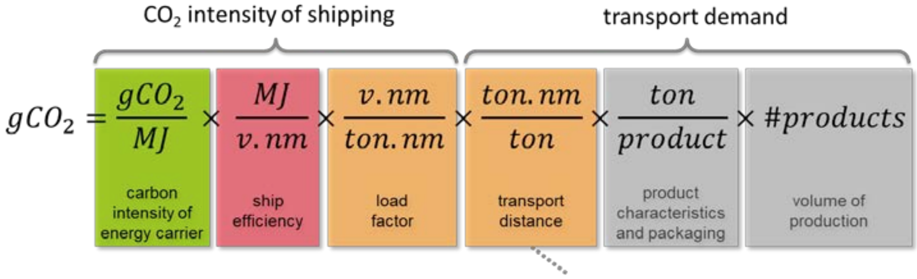



Figure 6 Breakdown of $CO_2$ emission sources from shipping.

In the following sections, emission reduction measures of all the above mentioned categories, except for the grey coloured categories, are presented:
- Alternative energy carriers and power generation,
- Energy efficiency and aftertreatment,
- Operations and logistics.

## 4.3 Alternative energy carriers and power generation

The IMO ambition to reduce $CO_2$ emissions from ships can be approached by ship powertrain technology and fuel type selection. Interesting technology and fuel combinations are the ones that have the potential to result in zero-emission shipping. In the following sections, first a brief overview of the main fuel conversion technologies is given. Then, zero-emission vessel (ZEV) options for several ship categories are reviewed based on the work published by Lloyd's and UMAS 2017.

### *4.3.1 Internal combustion engine (ICE)*

The one technology that is wide-spread in use on vessels and has proven its reliability is the ICE. These vessels mostly use fossil fuels to combust in their engines. To reduce CO2 emissions, however, alternative fuels from sustainable sources are necessary, such as sustainable biofuels and synthetic fuels (e.g. ammonia, hydrogen, methanol).

The introduction of synthetical produced electrofuels in general might deliver a solution for the GHG-problem utilizing the quickly growing surpluses of renewable energy of solar and windfarms. An extensive review of production costs has been published by Brynolf et al., 2018. A crucial factor in the timelines of a such introduction is the effective global pricing of GHG-emissions.

Such fuels that are suitable for use in these combustion engines are many. Some of the often referenced fuel candidates for future shipping are: ammonia, hydrogen, methanol, and biofuels. The use of ammonia and hydrogen obviously have zero CO2 emissions associated from tank to wake. In an ICE also other emissions are produced, such as $NO_x$, Particulate Matter (PM), and depending on the used fuel also $SO_x$. These emissions can be reduced in for instance aftertreatment systems, which is explained in more detail in the next section. In the context of hybrid electric powertrain systems, the ICE typically is the main power generator. Several options for ICE engines (such as the use of $H_2$) are suitable as retrofit option for existing systems. The economic viability of such a retrofit depends on the required investments in tank infrastructure and engine reconfiguration and the remaining economic lifetime of the vessel).

### *4.3.2 Fuel cells (FC)*

Fuel cells are a relatively new technology to the shipping domain. Inside the fuel cell, unlike in an ICE, fuel and oxidizer react via a catalytic process that converts the energy potential directly into electricity. None of the emissions that ICE's typically produce, such as $NO_x$, $SO_x$, PM, are emitted by the FC except for water. The choice of the fuel and the type of fuel cell technology are related to each other. The most suitable fuel cell types are expected to be the low temperature PEMFC for use with hydrogen and the high temperature SOFC for use with ammonia and methanol [CE Delft 190377]. Currently, ship powertrains including a FC are either in a research or a demo phase in small passenger ships or ferries [CE Delft, UMAS, 2019]. The CO2 footprint of the synthetic fuels (ammonia, hydrogen, methanol) need attention to reduce the well to wake CO2 emissions.

### *4.3.3 Batteries*

A battery is an energy storage technology and not a fuel conversion technology like an ICE or a FC. The lithium-air battery is the best performing regarding energy density and lifetime. In an electrically driven propulsion system, the role of a battery depends on the architecture of the system [CE Delft, UMAS, 2019]:

- In hybrid ships the batteries are used in conjunction with an ICE to flexibly adjust the ICE performance. In this configuration the batteries are charged by the ICE and not from the power grid. This option can be valuable for ships that have large load variations in their operational profile. In this way, the ICE can operate at its high efficiency point to reduce fuel consumption and the ICE can operate longer at stationary points without load transients, which is also beneficial for fuel consumption and pollutant emission reduction.
- In plug-in hybrid ships the batteries are also used in conjunction with an ICE like in hybrid ships. However, the batteries are charged from the grid instead of the ICE. The battery power is meant to be used only for specific operations such as manoeuvring.
- In full electric ships the batteries are the sole supply of power to the entire propulsion system and the auxiliary systems. Also here, the batteries are charged from the grid.

These electrically driven propulsion systems including a battery are at early application phase and the current potential to apply for ships is limited due their power requirements and operating profile. Also here, the $CO_2$ (and possibly also $NO_x$, $SO_x$, and PM) emissions related to the production of batteries and the production of the shore electricity need attention for the overall goal of reducing well to wake emissions.

### *4.3.4 Zero emission vessels (ZEV)*

At the moment, the comparison of ZEV technologies is often done as a desk study with the help of simulations. The results of such studies can be heavily dependent on the assumptions and the considered ship type and operation. Therefore, it is important to incorporate a variety of parameter variations to arrive at more reliable results. A study by Lloyds and UMAS (2017) on the profitability of ZEV options shows interesting results for different fuel scenarios and various ship types that can be related to the Belgian fleet.

Seven ZEV technologies are compared to a heavy fuel oil (HFO) baseline, namely:

1. Biofuel ICE,
2. Ammonia ICE,
3. Ammonia FC,
4. Hydrogen ICE,
5. Hydrogen FC,
6. Hydrogen FC + Batteries,
7. Battery electric.

Each of these ZEV technologies are investigated for three different fuel scenarios:

1. Green electricity: expensive electricity produced from renewable sources, cheap hydrogen produced from fossil sources, third-generation carbon neutral biofuels are available.
2. Green ammonia: carbon neutral ammonia widely available, cheap electricity from fossil sources, hydrogen produced from a mix of renewable and fossil sources, third-generation carbon neutral biofuels are available.
3. Green hydrogen: expensive hydrogen produced from renewable sources, FC technology becomes highly efficient and cheap hydrogen storage technology, cheap electricity produced from a mix of renewable and fossil sources, expensive ammonia produced from mix of expensive 'green' hydrogen and cheap electricity.

For all the combinations of the abovementioned ZEV technologies and fuel scenarios, cost calculations were performed for the following five ship types:

1. Bulk carrier, 53000 dwt,
2. Containership, 9000 TEU,
3. Tanker, 110000 dwt,
4. Cruise, 3000 dwt,
5. RoPax, 2250 dwt.

These profitability simulations resulted in biofuel ICE as the most profitable option in all scenarios for all the ship types. The close second became ammonia ICE, followed by ammonia FC and hydrogen ICE. An overview of the relative profitability outcomes is presented in Figure 7. The order of profitability of the ZEV technologies is the same for each ship type (not shown in the figure).

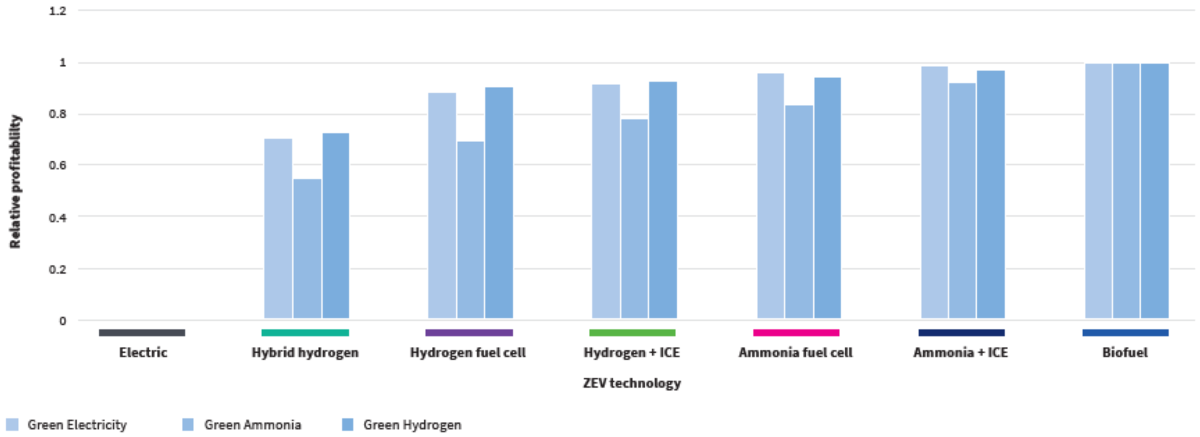



Figure 7 The relative profitability of ZEV technologies aggregated for all ship types and fuel scenarios. Taken from [Lloyds, UMAS, 2017].

It is important to note that in all the simulated scenarios, the ZEV options are less profitable than the HFO reference ship. This means that policy and regulations are important drivers for change instead of market forces.

The study also shows that capital costs of storage and the associated revenue loss due to reduced cargo space are important aspects that affect the profitability results, especially for technologies that include batteries and hydrogen. To investigate the sensitivity to these parameters, the reference range of the ships was reduced, however, the ship would in that case require more frequent bunkering. Reduced range results show that biofuel ICE is still the most profitable in all cases and for most ship types both hydrogen ICE and hydrogen FC are closer to the ammonia variants. With an 80% range reduction, even the battery electric technology becomes more profitable than the ammonia and hydrogen options for the cruise and RoPax ships.

#### *4.3.5 Cold Ironing*

A specific solution to reduce emissions from shipping in port areas is the use of cold ironing. In this process, shoreside (electrical) power is used when the ship is at berth as a replacement of (part of) use of the main and auxiliary engines. The measure leads to less emission of air pollutants, and can also have a positive effect on GHG emissions (dependant on the electric power source).

Cold ironing is already well developed for inland navigation vessels and small-scale maritime vessels (such as short-distance ferries). For larger vessels, cold ironing is in a development stage, in which currently some first pilots are conducted. Important issues are the development of standards for shore connections on ships, the needed investments on both the vessel and shore side and the effects of the power demand of vessels on the local energy grid.

#### *4.3.6 Impact of fuel choice on other emissions*

Switching to fuel with a lower sulphur content will reduce $SO_x$ emissions, for instance from Heavy Fuel Oil (HFO) to Marine Gas Oil or Marine Diesel Oil (MGO/ MDO) or to very low sulphur fuel oil (VLSFO with ≤0.5%Sulpher) or Ultra-low sulphur fuel oil (ULSFO with ≤0.1%S).

Switch to an alternative energy carrier, such as methanol or LNG. These engines automatically comply with the $SO_x$ regulations due to the absence of sulphur in the fuel. Depending on the engine technology, these engines can comply to the Tier III $NO_x$ level, with or without aftertreatment.

Switching to ammonia may cause ammonia slip and formation of N2O (which is a GHG gas).

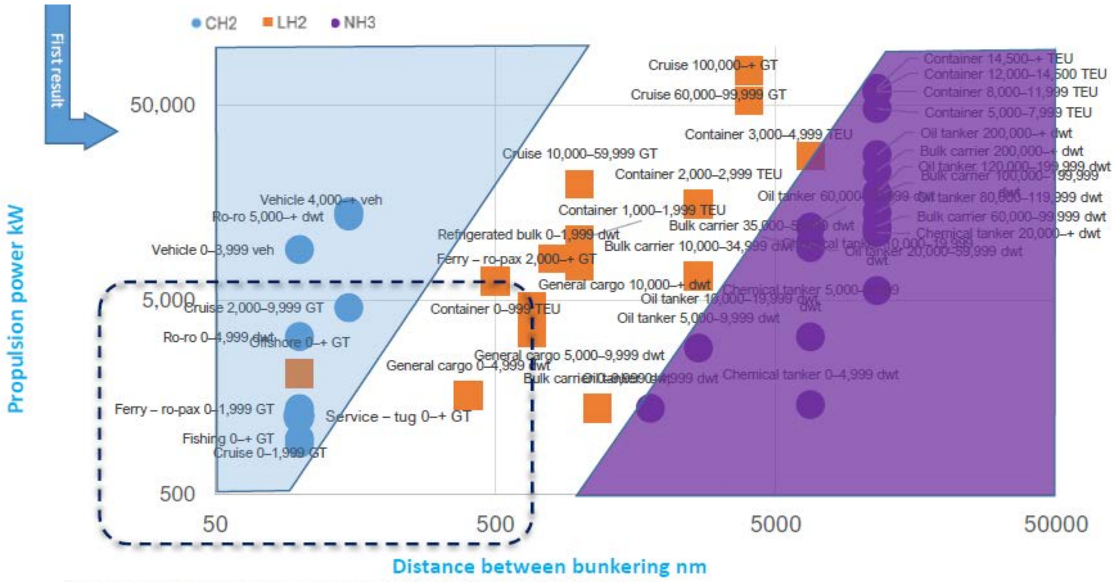
#### *4.3.7 Applicability for the Belgian fleet*

The attractiveness and applicability of different alternative energy solutions depend on several KPIs (TNO 2020), including:

- Technical aspects of the vessel:
  - ship size (dwt);
  - engine characteristics;
  - bunker tank size;
  - layout of the vessel.
- Operational characteristics:
  - function of the vessel (freight, passenger, other);
  - average sailing speed;
  - operational hours per year;
  - sailing pattern (fixed route or widespread reach);
  - average time between bunkering.

The above-mentioned aspects will influence the financial (CAPEX & OPEX), operational (supply side availability, flexibility to switch bunkering fuel) and other (i.e. safety) consequences of switching to alternative fuels.
An analysis for Hydrogen Europe of the attractiveness of zero emission energy carriers for different ship types concluded that ship types with relative short distance and/or point-to-point sailing patterns (port vessels, inland vessels, RoRo) are suitable for hydrogen or battery-electric (see figure 8) (Hydrogen Europe 2020).

Most midrange shipping markets have vessels with over-dimensioned tank capacity, which allows them to bunker alternative fuels such as methanol or LNG instead of HFO/MDO without serious adjustments to the bunker frequency, sailing pattern, or tank capacity/ship design (TNO 2020). For ammonia, less information is available on the suitability. Given the relative high density of the fuel, it is considered as a zero-emission option for midrange ships




** Outcome of Hydrogen Europe comparison tool illustrates the division in ship types*
*** Fuel solutions assuming that hydrogen based fuels are produced from CO2 from direct air capture.*

Figure 8 Optimal zero emission fuel solution versus ship type. CH2 is compressed hydrogen, LH2 is liquid hydrogen, NH3 is ammonia. REF: Hydrogen Europe, Strategic Research and Innovation Agenda, July 2020.
https://hydrogeneurope.eu/sites/default/files/20200703%20Final%20Draft%20updated%20SRIA%20HE-HER.pdf

Larger, globally operated vessels, such as large tanker vessels or bulk carriers are less suitable for alternative energy carriers, and are only expected to make a shift in the long term (TNO 2020).

In summary, on high level, the profitability of ZEV options tend to have the same ranking for every ship type as presented in Section 4.3.4. However, if one takes a closer look to a specific vessel with its technical aspects and operational characteristics (such as, function of the vessel, bunker tank size, bunker frequency), then the technological applicability of a certain combination of an energy conversion technology and a fuel might be more attractive than others. Eventually, the applicability must be evaluated on a ship by ship basis.

## 4.4 Energy efficiency and aftertreatment

### *4.4.1 Improvement of frictional resistance of the vessel*

Several measures can be taken to affect the currents around the vessel. This includes the use of friction-reducing coatings to hydrodynamic modifications [Bouman et al, 2017, Van den Berg, 2018]:

- *Antifouling and low friction hull coating* can be used on existing vessels to lower the frictional resistance of a ship and thus save fuel consumption. Literature shows a large range in the effects with potential savings between 1.5% and 4.5%.
- *Hull air lubrication* is done by a system injecting air on the wetted flat part of the hull in order to reduce the hull resistance. The system creates an air layer between the flat bottom part of the vessel and the sea water and therefore results in reduced fuel consumption due to reduced resistance. A range of 2.5% to 15% emission reduction may be achieved.
- *Hull design measures* focus primarily on reducing resistance during operation and are primarily applicable for new build vessels. The results indicate that novel hull design can contribute considerably to $CO_2$ emissions reduction (2% to 30%).
- Another trend in new build vessels is *increased size of the vessels*. This reduces emissions per transported unit through economies of scale. Particularly in container shipping vessels have increased in size in recent decades for deep sea shipping. This leads to savings of 10% to 30% $CO_2$-emissions.

### *4.4.2 Improvements of the ship propulsion system*

*Propulsion improving devices* (PIDs) are different ducts, pre-swirl fins, fin on hull, rudders, caps, contrarotating propeller or other modifications made to the hull or propeller in order to improve efficiency. Depending on the device, the main goal for these devices is to reduce the fuel consumption by improving the flow around the hull or propeller. The three main places to do modifications are in front of the propeller, behind the propeller or do modifications on the propeller or cap. Pre-swirl devices aim to improve the propeller inflow conditions, ducts may improve propulsion efficiency by improving the propeller inflow and post-swirl devices are used to recover parts of the rotational energy in the propeller slip stream. Literature finds expected savings between 1.5% and 6.5% depending on the measures and the ship type [Van den Berg, 2018].

*Wind assistance* in shipping has the objective to recover thrust power from wind in order to reduce the main engine load while maintaining the same speed. Wind assistance on ships is in development. Several types of wind assist are being investigated, including kites, hard or soft sails and Flettner rotors. Currently several pilots are sailing using different technologies. The energy savings depends on the ship type and the sailing route. Savings found in literature range from 5% to 20% (Bordogna 2020, IMO 2020),

### *4.4.3 Emission control systems*

*Aftertreatment systems* reduce the pollutant concentrations (except for $CO_2$) in exhaust gases after the creation of these pollutants inside the power generator (for instance a combustion engine). In order to comply with $NO_x$, $SO_x$, and PM regulations, vessel owners can undertake one of the following aftertreatment options:

- SCR Catalysts for $NO_x$,
- Scrubbers for $SO_x$,
- Particulate filters for PM reduction.

These aftertreatment systems can be integrated in a single ship to achieve simultaneous reductions of all the three emissions.

*In-engine control* reduces the amount of pollutant creation during the combustion process inside the engine.

- Exhaust Gas Recirculation (EGR)Water injection.

These in-engine reduction methods can be applied in conjunction with aftertreatment systems to obtain for instance large reductions of $NO_x$ by the application of EGR in combination with a SCR, and a simultaneous reduction of PM by the use of a particulate filter, whereas the use of EGR only would tend to increase the emission of PM.

## 4.5 Operations and logistics

### *4.5.1 Slow steaming*

The relationship with speed of a vessel's fuel consumption for propulsion is typically an exponential one. An assessment of DNV GL for IMO found as a rule of thumb that a speed reduction of 10% results in a total fuel saving of approximately 19% [GLOMEEP 2020].

Ship operators do not always sail at a specific speed point, but rather at a specific engine load which is associated with a general operating speed with no current. Actual speed through water will be affected positively or negatively by conditions such as wind and waves (see for example Figure 9).

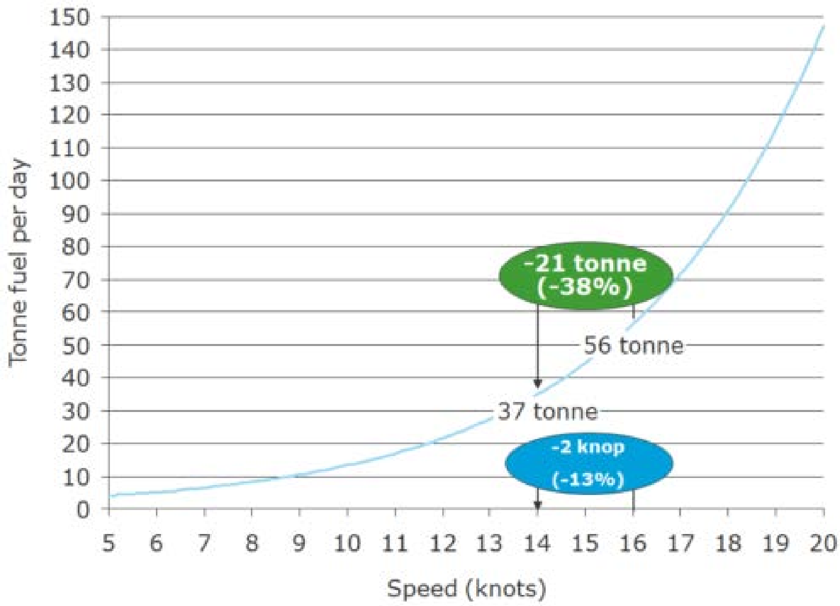



Figure 9 Typical relation between vessel speed and fuel use per day [GLOMEEP, 2020].

Speed reduction or slow steaming is a common operating feature in shipping as a way to lower operating expenditures by reducing fuel consumption. The economic viability of slow steaming is affected by several factors, such as freight rates, bunker costs and interest rates [Ma, 2014]. Policy measures, such as carbon prices will also have an effect on this decision. However, a study on the implementation of different measures for a Post Panamax bulk carrier found that the current of levels of $CO_2$-prices (euro 50 per ton), hardly affects the carrier's decision [Van der Berg, 2018].

### *4.5.2 Application of monitoring tools*

Ship operators are using many different monitoring tools as part of their operations. Application of sensors and engine room related monitoring systems can record how the ship's propulsion and energy system are functioning and can give insight in the overall sailing profile of the ship. Furthermore, it can provide insight on the current state of components and whether maintenance is needed [TNO 2020].

Combining ship related sensor systems with route optimization software can have additional benefits. The software can give advice on the optimized speed an engine load given the nautical conditions. Furthermore, the systems can advise for switching off engines or systems, that are not strictly necessary. Monitoring systems can provide real time or offline advice on whether and how things can be improved. For example, online there is a display for the helmsman, which shows how efficiently the systems are running. When offline, a specialist will generally analyze the data and draw up a report of what could possibly be done better. This can be done by instructions to the crew or by better adjustment of the control system.

Monitoring tools are not only used in an operational setting, but can also be used on the level of the whole fleet. This provides fleet owners with insight into overall GHG performance and allows them to make decisions on optimized speed and benchmark individual ships.

Several commercial monitoring tools are already in the market. However, many systems are still stand alone and do not give an integrated overview of the status of the vessel. Forthcoming research focusses on developing a digital twin of the vessel. The essence of the digital twin is a virtual representation of the ship and all relevant systems connected to the physical representation, the ship as it is built (Waterborne 2020). There is uncertainty on the contribution of digital twins to emission reduction. More research is needed for this.

### *4.5.3 Just-in-time sailing*

Short transit times are important competitive factors in liner shipping of containers and bulk goods. Improving real time exchange between ship systems and terminal operators in the port can provide operators better insight in the time in which a quay is available in the port. This usually means that ships can reduce their speed so that they arrive just in time, thus enabling the operator to save fuel and lower emissions (TU Delft, Erasmus University and TNO 2018). Based on an analysis of inbound container vessel movements for the port of Rotterdam, a potential annual $CO_2$-saving of 4% (0.13 Mton) can be accomplished if vessels are continuously informed during the last 12 hours before arriving. Furthermore, just-in-time sailing can result in shorter waiting times in anchorage areas for ships sailing to Rotterdam (Port of Rotterdam 2018).

In order to facilitate just-in-time operations, data should be shared between different stakeholders. Data exchange between companies currently hardly exists [TU Delft, Erasmus University and TNO 2018]. To stimulate data exchange between different stakeholders, shared (and public) requirements need to be specified, including [TNO, Marin and TU Delft 2017]:

- an overall (governance and architectural) framework for the information infrastructure for inland autonomous shipping;
- standards for data models and interfaces;
- the availability of adequate communication network infrastructures; and
- a field-lab to demonstrate viability of high-level information structure and to stimulate further development of standards on data models and interfaces.

## 4.6 Cost efficiency of measures

As part of the 4$^{TH}$ IMO GHG study, an analysis was made on the marginal abatement costs of several different reduction options. Table 3 shows an overview of the potential reduction of the costs (in US Dollar) per ton $CO_2$ that could be achieved. The table shows that there are several measures that lead to cost reduction. This includes measures such as hydrodynamic optimisation (such as the use of side thrusts to optimise water flows), improved maintenance and better on-board energy management. Other options may lead to a significant cost increase such as use of alternative zero-emission energy carriers.

Table 3 Cost efficiency and abatement potential (interest rate: 4%, lifetime: 25 years, price of fuel oil: 375 USD/tonne) for 2030.

| Technology group | Reduction option | Marginal abatement Costs (US$/ton $CO_2$) | $CO_2$ abatement potential (%) |
|---|---|---|---|
| Group 10 | Optimization water flow hull openings | -119 | 1.64% |
| Group 3 | Steam plant improvements | -111 | 1.30% |
| Group 6 | Propeller maintenance | -102 | 2.20% |
| Group 9 | Hull maintenance | -92 | 2.22% |
| Group 12 | Reduced auxiliary power usage | -61 | 0.40% |
| Group 8 | Hull coating | -53 | 1.48% |
| Group 2 | Auxiliary systems | -41 | 0.87% |
| Group 1 | Main engine improvements | -35 | 0.25% |
| Group 13 | Wind power | 6 | 0.89% |
| Group 16 | Speed reduction | 17 | 7.38% |
| Group 5 | Propeller improvements | 21 | 1.40% |
| Group 11 | Super light ship | 54 | 0.28% |
| Group 4 | Waste heat recovery | 69 | 1.68% |
| Group 7 | Air lubrication | 105 | 1.35% |
| Group 15A | Use of alternative fuel with carbons | 258 | 5.54% |
| Group 15b | Use of alternative fuel without carbons | 416 | 0.10% |
| Group 14 | Solar panels | 1,186 | 0.18% |

Source: CE Delft et. al. 2020.

Note that the long-term cost development of alternative energy carriers is very uncertain and will depend on the development of both the investment costs of the system (CAPEX) and the fuel costs (OPEX).
The investment costs of different energy carriers will largely depend on the development of technology. Important factors in this development are technology improvements in battery packs and fuel stacks.
For fuel cost, a main uncertainty is the price development of green hydrogen (based on electrolysis of green electricity) and subsequently the step towards e-fuels. For some fuels, such as methanol, a further uncertainty is the price of a sustainable source of $CO_2$ (direct air capture). As an example, the figure below presents an overview of the price development of e-methanol for three different prices for green electricity and three scenarios for sustainable production of $CO_2$. The uncertainty in these price levels makes the future price level of e-methanol uncertain.

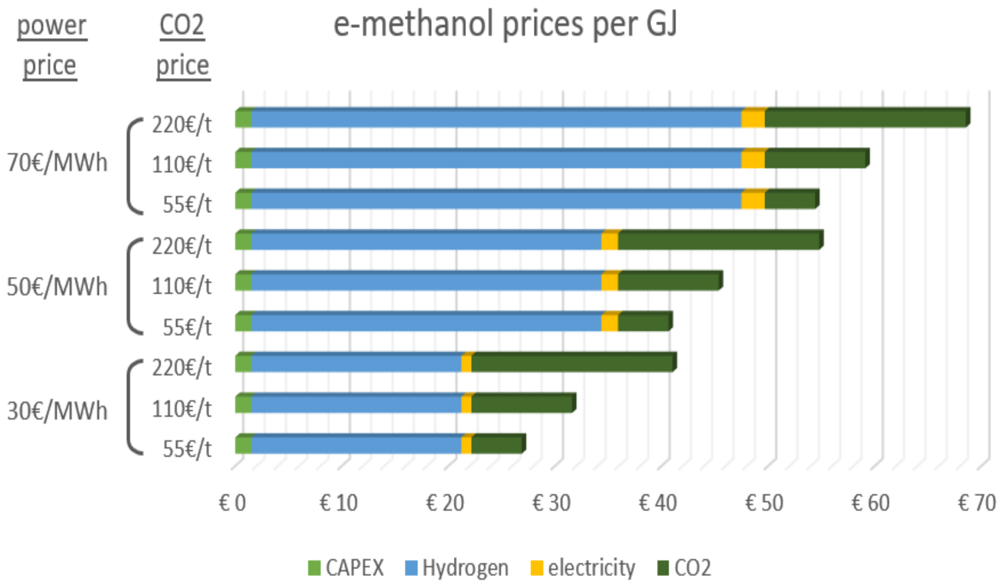



Figure 10 Price of e-methanol for different scenarios of feedstock costs (TNO 2020).

# 5 Options for underwater radiated noise reduction

## 5.1 Underwater noise pollution and regulation

Over the past decades, underwater noise produced by human (anthropogenic) activities has become widely recognised as a form of pollution of the marine environment. Several international agreements address underwater noise impacts on marine life [Lewandowski & Staaterman, 2020]. For example: the European Union [EC, 2008; EU, 2017] has, in its Marine Strategy Framework Directive, included underwater noise as one of the descriptors of ‘Good Environmental Status’.

Ship traffic is generally considered the main source of anthropogenic low-frequency ambient noise in the oceans. Shipping noise makes the largest contribution to the total acoustic energy in the Dutch part of the North Sea, up to 10 kHz [Sertlek et al, 2019]. Though there are still significant knowledge gaps, more and more evidence of the effects of shipping noise on marine life is emerging [Rolland et al, 2012; Erbe et al, 2016; Kunc et al, 2016; Weilgart, 2018; Erbe et al, 2019].

Donald Ross suggested in 1975 that low-frequency ambient noise levels must have risen by about 10 dB since 1950, because the total number of ships had more than doubled and ship sizes increased, and predicted a further increase by about 5 dB over the next 25 years [Ross, 1975]. A significant increase was observed in certain areas [McDonald et al, 2006, Andrew et al, 2011], with the rate of increase slowing down over the past decade, but evidence for a continued global trend in ambient noise is lacking [Miksis-Olds & Nichols, 2016], the continued growth in capacity of the global shipping fleet leads to an increased concern about impact on marine life [Frisk, 2012; Kaplan & Solomon, 2016; Southall et al, 2018]. Various proposals for management and regulation of shipping noise have appeared [Heise et al, 2017; Vakili et al, 2020], see also § 5.3.

## 5.2 Underwater radiated noise from ships

### *5.2.1 Metrics and measurement*

The terminology for underwater noise is standardized in [ISO 18405: 2017]. Based on experience in the naval field [NATO STANAG 1136] and a national standard [ANSI/ASA S12.64-2009/Part 1], ISO has published standard procedures for measuring ship radiated noise in deep water [ISO 17208-1: 2016; ISO 17208-2: 2019] and is working on an standard for shallow water measurements.

Open literature publications of ship underwater radiated noise measurements, e.g. [Arveson & Vendittis, 2000; McKenna et al, 2012; Simard et al, 2016; Hannay et al, 2016; Veirs et al, 2016; Jansen & de Jong, 2017] generally do not follow the same standard, which means that a comparison of published levels is not always possible. The same holds for the limits for ship radiated noise published by ship classification societies (see § 5.3.3).

The ship radiated noise reported by different studies is not always compatible because different approaches have been chosen to obtain radiated noise metrics from measurements of sound pressure with sensors (hydrophones) at different distances from the ship and in different environments.

Many acoustic metrics are expressed in decibels (dB). The decibel is a logarithmic numerical scale to compare the values of like quantities. Because it is used for different quantities, confusion may arise. Referring to [Chapman & Ellis, 1998], the following basic principles should be kept in mind:

- The standard reference pressures used in underwater acoustics and in-air acoustics are not the same, hence it is incorrect to compare dB-values of sound levels in air and water.
- The acoustic metrics for radiated sound (i.e. source level or radiated noise level, as defined by ISO) and for received sound (sound pressure level) are not the same, hence it is incorrect to compare source level with received sound level at an unspecified distance from the source.
- “It is unwise to assume that the auditory experience of any animal would be the same as that of a human exposed to the same sound pressure level” [Chapman & Ellis, 1998]. Yet in broad terms, our hearing physiology and stress response are not radically different from other animals, especially mammals.

### 5.2.2 *Sources of underwater radiated noise*

The basic principles of ship underwater radiated noise are well known [Urick, 1975; Ross, 1976; Janssen (ed.), 1976; Buiten (ed.), 1986]. But ship design varies significantly, not only between ship classes but also between individual ships of the same class. While generic trend estimations of radiated noise based on ship class, dimensions and speed are useful for overall estimations of the contributions of classes of ships to shipping sound in the oceans, the design details of specific vessels must be analysed to design noise reduction measures and to quantify their effectiveness [Spence & Fischer, 2016].

Most commercial vessels have been designed without consideration for underwater noise. However, underwater radiated noise reduction has been extensively studied for naval vessels, since the use of sonar for detecting these, and for fishery research vessels, so that marine life would not be startled during biomass surveys [Mitson, 1995]. The most common noise generating mechanisms are classified as ‘propeller noise’ and ‘machinery noise’, where propeller noise is generally the dominant source for commercial vessels sailing at or around design speed.

The dependence on design details and on ship speed is clearly illustrated by the results of detailed measurements on a cargo ship in Figure 11, from [Arveson & Vendittis, 2000]. The radiated noise contains a combination of broadband noise and tones. At the lowest speed, the radiated noise below 200 Hz is dominated by the ship’s service diesel generator, which generates a series of 6-Hz harmonics. The generator noise is independent of ship speed. At the highest ship speed, the radiated noise is dominated by tonal (‘blade rate harmonics’) and broadband propeller noise, combined with a few tones at firing rate harmonics of the propulsion diesel engine.

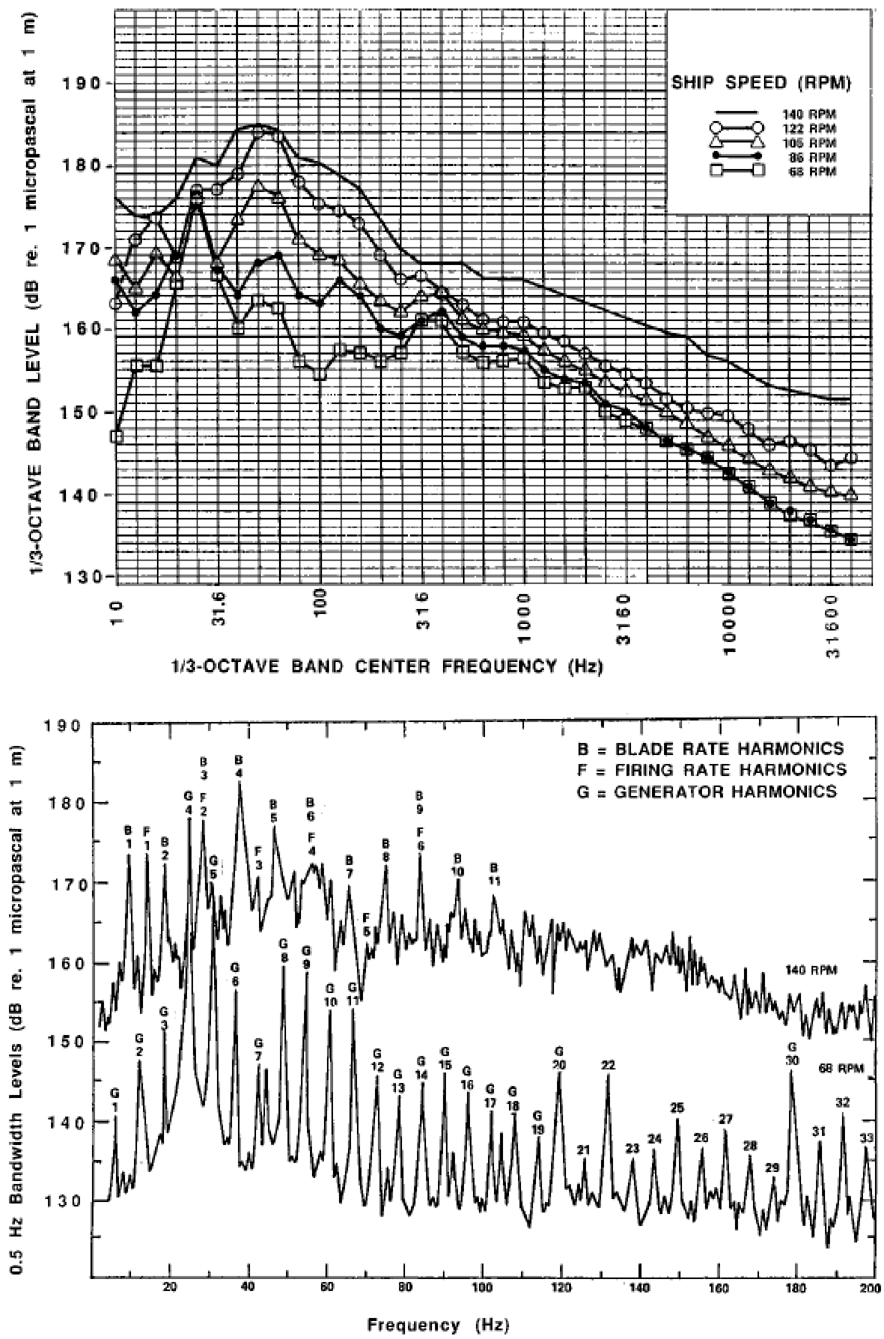



Figure 11 Keel-aspect radiated noise level spectra of M/V Overseas Harriette, from [Arveson & Vendittis, 2000]. Top: one-third octave band spectra at five ship speeds (8, 10, 12, 14, 16 knots). Bottom: narrowband (0.5 Hz) spectra at the lowest and highest speeds.

### 5.2.3 *Propeller noise*

The main source mechanism of propeller noise is ‘propeller-induced’ cavitation. When a ship’s propeller rotates through the water, it generates the pressure difference across its blades that propels the ship. Where the under-pressure drops below the local vapour pressure, the water vaporizes locally. This creates cavities (‘bubbles’ and ‘bubble sheets’), which implode violently when they move out of the low pressure area. These ‘cavitation’ processes generate tonal noise at blade rate harmonics (due to the rotation of the propeller blades in the inhomogeneous wake flow) as well as broadband noise (due to the sharp implosions of the cavities). Various cavitation types can occur, see Figure 12.

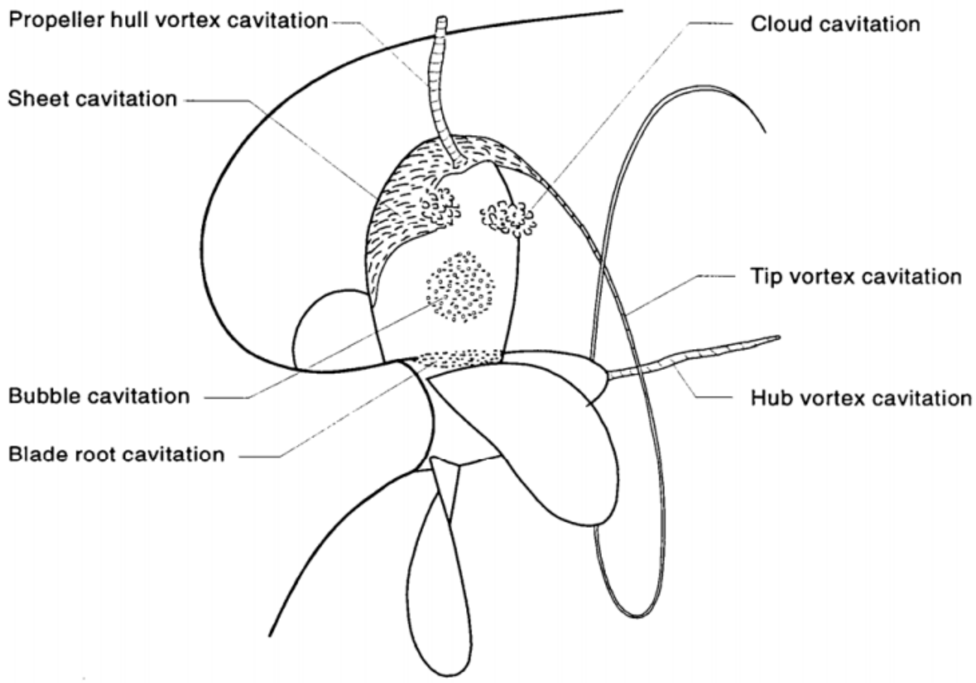



Figure 12 Cavitation types occurring on ship propellers [ITTC, 2002].

The main parameters that affect propeller cavitation performance are rotation rate (rpm) and propeller diameter, but it also strongly depends on the ship resistance (propeller thrust loading), uniformity of the inflow into the propeller (the hull wake) and on blade design [Brown, 1976; Ross, 1976; Leaper & Renilson, 2012; Leaper et al, 2014; Spence & Fischer, 2016].

### 5.2.4 *Machinery noise*

The second relevant group of ship radiated noise sources consists of the onboard machinery for propulsion (e.g. engines and gear boxes) and auxiliary tasks (e.g. power generators, pumps and air-conditioning equipment). All machinery items will transmit vibrations to their foundation structure, as well as radiate airborne noise in the machinery spaces. This noise will travel though ship structure and air to the hull, where it will be radiated into the water as radiated noise design [Urick, 1975; Ross, 1976; de Jong, 2002; Spence & Fischer, 2016].

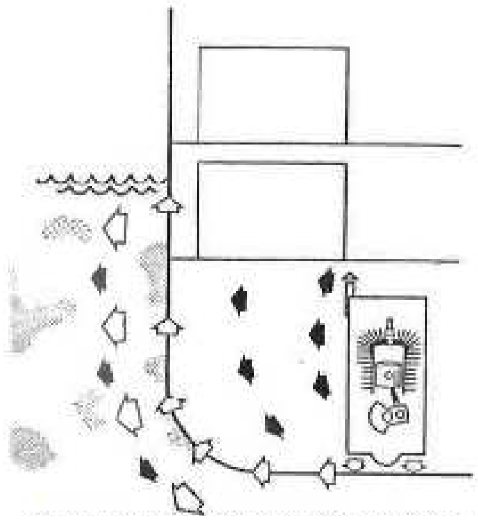


Figure 13 Airborne noise and structure-borne noise transmission from machinery to the hull leads to hull vibrations and underwater noise radiation, with structure-borne noise generally being the most important of the two.

## 5.3 Initiatives towards ship underwater radiated noise reduction

Various international initiatives provide relevant information about options for mitigation of ship underwater radiated noise.

### *5.3.1 NOAA-Okeanos*

In 2004, the US National Oceanic and Atmospheric Administration (NOAA) hosted the international symposium “Shipping Noise and Marine Mammals”, bringing together regulatory and scientific communities with the shipping industry [Southall, 2005]. This was followed in 2007 by a second symposium “Potential Application of Quieting Technology on Large Commercial Vessels”, which focused specifically on technical aspects, costs, benefits, and potential incentives for various noise reduction options [Southall and Scholik-Schlomer, 2008]. Building on these efforts Okeanos-Stiftung für das Meer convened a workshop in Hamburg in 2008 [Wright, 2008], which resulted in a “call for initial global action that will reduce the contributions of shipping to ambient noise energy in the 10-300 Hz band by 3 dB in 10 years and by 10 dB in 30 years relative to current levels. This goal would be accomplished by reducing noise contributions from individual ships.” Though this call has not been formally accepted by regulatory bodies, the scope of potential environmental implications of, and solutions to, shipping noise is substantial and will require concerted and sustained international efforts [Southall et al, 2018].

### *5.3.2 International Maritime Organization*

In 2008 The IMO MEPC 58 approved the inclusion of a new high priority item in the work program of the Committee on “Noise from commercial shipping and its adverse impact on marine life.” A correspondence group was formed, and its report was discussed at MEPC 61. MEPC 61 agreed that the propeller is the main source for ship generated underwater noise and that future research programmes should focus on the propeller and the relationship between cavitation and the cause of underwater radiated noise.

In 2014, IMO approved non-mandatory technical guidelines on reducing underwater noise from commercial shipping, to address adverse impacts on marine life

[IMO MEPC, 2014]. Given the complexities associated with ship design and construction, the Guidelines focus on primary sources of underwater noise, namely on propellers, hull form, on-board machinery, and various operational and maintenance recommendations such as hull cleaning.

The Marine Environment Protection Committee (MEPC) at its 72nd session in April 2018 noted a number of submissions in relation to underwater noise. The need for further research to better understand the impact of underwater noise from shipping as opposed to underwater noise from other sources was raised by a number of delegations. Member States have been encouraged to continue to share their experiences in dealing with the reduction of underwater noise from shipping [IMO MEPC, 2018; 2019].

#### 5.3.3 *Ship classification societies*

Major ship classification societies, e.g. [DNV GL, 2018; BV, 2018; Lloyd's Register, 2018], have established limits for ship radiated noise. Their methodologies and standards for measuring have not been harmonized, which may explain differences in the various limits.

#### 5.3.4 *AQUO-SONIC and PIAQUO*

The EU FP7 research programmes AQUO [Audoly et al, 2017] and SONIC [Prins et al, 2016] jointly produced one document with guidelines for regulation on underwater noise from commercial shipping [AQUO-SONIC, 2015]. Since 2019, this work is continued in the EU-Life project PIAQUO[5], which aims at reducing the acoustic impact of maritime traffic and adapting it in real time to the ecosystems.

#### 5.3.5 *Transport Canada*

Transport Canada, in collaboration with the marine industry, academia, Indigenous groups, environmental organizations, other government departments, the United States and the broader international community, is assessing, testing and implementing measures to reduce the impacts of marine traffic on at-risk whale populations, in particular the Southern Resident killer whale, and the North Atlantic right whale. In this context, Vard Marine Inc. prepared a report on ship underwater radiated noise reduction for the Innovation Centre of Transport Canada [Kendrick & Terweij, 2019]. The findings have been reported to IMO [IMO MEPC, 2019]. In 2019, Transport Canada organised an international workshop "Quieting Ships to Protect the Marine Environment" [Bahtiarian, 2019] in London and a follow-up workshop in Canada [TC, 2019].

#### 5.3.6 *ECHO programme*

The Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) program is aimed at better understanding and managing the impact of shipping activities on at-risk whales throughout the southern coast of British Columbia. One of the key focus areas of the ECHO Program is underwater noise from shipping activities and finding ways to reduce it.

In 2017, the ECHO program carried out a two-month voluntary vessel slowdown trial to determine whether slowing to 11 knots was an effective method for reducing underwater radiated vessel noise [DFO, 2017; MacGillivray et al, 2019; Joy et al,

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[5] http://life-piaquo.eu

2019; Williams et al, 2019]. The results of this trial are summarized in Section 5.6. The ECHO Program commissioned a study to identify technical ways to make vessels quieter [Hemmera, 2016]. The Vancouver Fraser Port Authority's EcoAction Program offers discounted harbour dues to vessels that have adopted quiet notations from ship classification societies Bureau Veritas, DNV-GL and RINA (§ 5.3.3).

In May 2020, the ECHO program reported the results of a vessel noise correlation study [MacGillivray et al, 2020], using data from the ECHO Program vessel source level database (2015-2018) and different databases to investigate correlations between vessel noise emissions, design characteristics and operating conditions for six major commercial vessel categories. It was found that vessel overall length was the main design characteristic and speed through water and actual draft were the main operational characteristics that have a strong correlation with underwater radiated noise in all vessel categories. No other general design characteristics that are publicly available through Lloyd's List Intelligence were found to have a significant correlation to vessel noise emissions.

#### *5.3.7 International Fund for Animal Welfare (IFAW)*

The non-governmental organization International Fund for Animal Welfare (IFAW) has actively reviewed the potential options for reducing underwater noise from large commercial ships [Leaper & Renilson, 2012; Leaper et al, 2014; Leaper, 2019].

## 5.4 Options for underwater radiated noise reduction

Guidelines for the reduction of underwater noise from commercial shipping [IMO MEPC, 2014; AQUO-SONIC, 2015; IMO MEPC, 2019] distinguish <u>design</u> and <u>operational</u> mitigation measures. This section presents a global overview of the various options. More details can be found in the mentioned guidelines and referred literature.

## 5.5 Noise mitigation in ship design

Generic analysis of ship underwater radiated noise, such as applied in § 3.3, do not provide the insights into the design details of specific vessels that must be analysed to implement noise reductions. Because of the large variety of ship designs within each ship type class, this must be done on a case-by-case basis [Spence & Fisher, 2017]. The optimal underwater noise mitigation strategy for any ship should at least consider all relevant noise sources [IMO MEPC, 2014], considering that any noise source that is at least 10 dB louder than the next loudest noise source dominates the noise output, such that the others become largely irrelevant.

Because the vast majority of current commercial vessels have been designed without consideration for underwater radiated noise, the first step towards achieving noise reduction will be to include guidelines, such as [IMO MEPC, 2014; AQUO-SONIC, 2015], in the design process. Developing and implementing noise control solutions is most cost effective and acoustically effective when performed during the vessel's design stage. Retrofitting the treatments always leads to additional costs, and some treatment approaches may not be possible because of space or other design restrictions [Spence & Fisher, 2017].

### *5.5.1 Hull*

The main factors through which hull design affects underwater radiated noise are:

- Resistance: optimisation of the hull form and the application of anti-fouling and low-friction coatings, for reduced resistance will reduce the required propulsion power at the same speed, which will generally lead to reduced propulsion noise (less propeller cavitation). Reduced resistance is also beneficial for energy efficiency and reduces emission of greenhouse gases, see § 4.4.1.
- Wake field: optimisation of the hull form with its appendages such that the wake field (in the propeller plane) is as homogeneous as possible, which will reduce propeller cavitation. Various technical solutions (fins, ducts) to improve the inflow into the propeller are proposed as *propulsion improving devices* (PIDs), since these are generally beneficial for energy efficiency as well, see § 4.4.2.
- Structure: optimization of the hull structure (mass, stiffness and damping) can potentially reduce the underwater radiation of structure-borne and air-borne machinery noise. Only relevant when machinery noise exceeds propeller noise.
- Hull treatments: air emission systems can be installed to reduce resistance (air lubrication), which likely reduce machinery noise radiation as well (decoupling the vibrating hull from the surrounding water). Decoupling can also be achieved by application of a flexible hull coating, see e.g. [de Jong, 2002]. Such decoupling techniques are used on naval vessels (submarines as well as surface ships) with stringent acoustic signature requirements.
- Appendages and openings (sea chests): improper design of appendages and hull openings (e.g. for cooling water intake) can lead to local cavitation or flow-induced noise [Ross, 1976; Blake, 2017].

### *5.5.2 Propellers*

Most ship propulsion systems provide thrust through one or more screw propellers. Propeller-induced cavitation is generally considered to be the main source of underwater noise of commercial vessels, particularly at higher speeds. All ships in the Belgian fleet (Chapter 2) are propeller-driven.

The propeller design [Kuiper, 2010; Carlton, 2012] generally starts with a given hull form and a required ship speed. Important goals of the propeller design are minimum power (optimum efficiency) and the correct rotation rate of the propeller (required by the engine). Propeller cavitation behaviour provides an important additional boundary condition, to avoid erosion damage and reduce noise and vibrations. Optimum propeller design involves model calculations of the flow around the hull and the propeller (computational fluid dynamics; CFD) and in some cases also scale model testing, services that are offered by several hydrodynamic institutes.

The main factors through which propeller design affects underwater radiated noise are:

- Number of propellers: distribution of the thrust over more than one propeller can reduce propeller loading and cavitation. Moreover, the wake flow into the propeller can be more uniform if the propellers are placed off the centre line of the vessel.
- Fixed or Controllable pitch: propeller blades can have fixed blade angles (fixed pitch) or adjustable blade angles (controllable pitch). Pitch control enables adjusting the thrust (and hence ship speed) independent of the rpm. Consequently, reducing the speed of a ship equipped with controllable pitch

propellers does not necessarily result in a radiated noise reduction. When the shaft speed can be controlled as well, the combination of shaft speed and propeller pitch can potentially be optimized with respect to cavitation performance and noise.

- Number of blades, blade area and shape (pitch and skew): no general guidelines can be given for these design parameters, since they need to be optimized against multiple requirements. However, it is advised to include cavitation behaviour and noise control as essential boundary conditions for the design process.
- Hub: hub cavitation (Figure 12) should be avoided as well. Technical solutions, such as propeller boss cap fins and cap turbines [IMO MEPC, 2019] could be considered.
- Azimuth thrusters: marine propellers can be placed before or after underwater pods that can be rotated to any horizontal angle (azimuth), increasing manoeuvrability and making a rudder unnecessary. A (diesel or diesel-electric) motor can either be inside the ship and connected to the outboard unit by gearing (L- or Z-drive), or the motor may be diesel or diesel-electric. Depending on the shaft arrangement, an electric motor is fitted in the pod itself. (‘podded propulsion’) This drive type allows for a more uniform inflow into the propeller, leading to improved cavitation behaviour, at the cost of a more direct connection between the motor and the water, leading to higher machinery noise radiation.
- Air injection: can be used for either reducing propeller cavitation by air injection directly into the cavitating region, or attenuating noise radiation by generating an isolating bubble ‘curtain’ around the propeller and its downstream flow

### *5.5.3 Alternative propulsion types*

The most effective solution to reduce ship underwater noise is to have the propulsor above the water, such as in sailing vessels. Solutions under development for wind assistance (wing sail, kite sail and Flettner-rotor concepts), reduce the amount of thrust to be generated by the ship’s propeller(s) and hence increasing energy efficiency and reducing emissions, see § 4.4.2. This will also likely reduce propeller cavitation and underwater radiated noise.

A *pump-jet*, *hydro-jet*, or *water jet* is a ducted propeller (axial-flow pump), or a centrifugal or mixed flow pump that produces a jet of water for propulsion. Water jets are used on high-speed pleasure craft (such as jet skis and jet boats) and other small vessels, on naval vessels (patrol boats, mine hunters, submarines and torpedoes) and on high speed ferries. The duct creates a more uniform flow into the propeller and shields direct underwater sound radiation from the propeller, which leads to lower underwater sound radiation than for an open propeller. On the other hand, the pump usually operates at a higher rpm than a propeller, resulting in blade rate tones at higher frequencies, and the splash of the water jet, when operated above the water surface generates bubbles and broadband underwater noise. Limited measurements on water jet propelled vessels, e.g. [Allen et al, 2012], seem to be inconclusive.

Some tugboats, drilling vessels, and other watercraft that require good manoeuvrability make use of a Voith Schneider propeller, a cyclo-rotor that provides instant thrust in any direction, so that the vessel does not need a rudder. This form of propulsion is potentially more quiet than standard propellers, but the authors are not aware of any data to support this.

### 5.5.4 *Maersk study*

Because there is no regulation on underwater radiated noise reduction for commercial ships, this has received limited attention and hence there is very little experimental evidence of the effectiveness of underwater noise control measures. Therefore, the study carried out by Maersk Line and Scripps Institution of Oceanography in 2017 [Gassmann et al, 2017] has received a lot of attention. In the years of 2015 and 2016, Maersk retrofitted eleven G-class container vessels to improve energy-efficiency. This retrofit included replacing the bulbous bow to reduce drag, derating the main engines for slow steaming and installing more efficient propellers with propeller boss cap fins to reduce cavitation. Scripps has made opportunistic recordings of the underwater noise of five of these vessels before and after their retrofit during transits in a shipping lane through the Santa Barbara Channel.

The measured reductions of the recorded sound pressure level were limited to a median of 0 dB in the low-frequency band (8 - 100 Hz) and a median of 2 dB in the higher-frequency band (100 - 1000 Hz).

The low-frequency sound radiation of surface ships is heavily affected by the so-called Lloyd’s mirror effect, which involves destructive interference between the source signal and its reflection from the sea surface. However, the average draft of the vessels during the post-retrofit transits was several meters deeper than before. Hence, reasoning that less destructive inference was expected due to this greater draft, it was concluded from this study that the source level (corrected for Lloyd’s mirror) of the five selected vessels was lower post-retrofit by a median of 6 dB in the low-frequency band (8 - 100 Hz) and a median of 8 dB in the higher-frequency band (100 - 1000 Hz). It was suggested that reductions may result from improved propeller cavitation behaviour, due to both the retrofitted propellers with boss cap fins, and due to propeller operation at greater depth where ambient pressure is higher. In the ECHO vessel noise correlation study report [MacGillivray et al, 2020] it was concluded that the deeper drafts were indeed associated with higher noise emissions. The greatest influence of draft was above 1000 Hz, where cavitation dominates the noise spectrum. However, [MacGillivray et al, 2020] also mention the competing influences of draft on acoustic mechanisms. The efficiency of sound radiation increases with increasing draft, due to reduced Lloyd’s mirror interference and the increased hull area in contact with the water. Propeller cavitation may increase with increasing draft, due to increased hull resistance, but the increasing depth of the propeller with increasing draft may lead to cavitation reduction.

### 5.5.5 *Machinery*

Propulsion engines are an unavoidable source of underwater noise radiation for ships (except when wind-driven). The main types of propulsion systems currently in the Belgian fleet are slow speed (2-stroke) diesel engines, medium and high speed (4-stroke) diesel engines, steam turbines and diesel-electric systems.

The technology required to reduce machinery noise is well-established. The main noise-control measures are (see Figure 14):

- installation of low-noise machinery
- installing machines on resilient mountings, or on resiliently mounted deck structures, to reduce the transmission of structure-borne noise;

- resilient suspension of pipes, cables etc. and the installation of flexible shaft couplings and bellows, again to reduce the transmission of structure-borne noise;
- installing machines in enclosures, to reduce the transmission of air-borne noise;
- using damping and absorbing layers on surfaces to reduce the transmission of structure-borne noise and airborne noise.

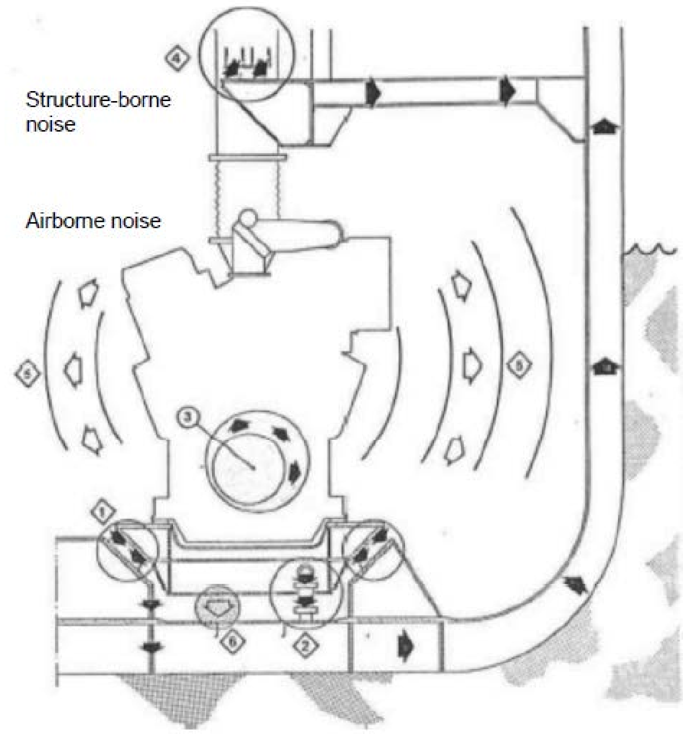


Figure 14 An example of the various (airborne noise and structure-borne) transmission paths for noise produced by machines: 1. Transmission through the resilient mountings; 2. Transmission through the cooling water connection, wiring etc.; 3. Transmission through the shaft coupling (flexible or otherwise) etc.; 4. Transmission through the attachments for the exhaust pipes (flexible or otherwise); 5. Radiated airborne noise; 6. Airborne noise transmission via the cavity below the engine.

An important requirement for effective resilient mounting is that the structures on both sides of the mount (machine foundations and feet) are designed to be highly resistant to vibration (have a high 'mechanical impedance').
The vast majority of commercial vessels is driven by 2-stroke engines. Due to their large weight and power 2-stroke engines need to be rigidly mounted. Medium- and high-speed 4-stroke diesel engines can be mounted elastically, but these usually require a gearbox which may require specific measures for the reduction of tonal sound. Steam turbines generate very low structure borne noise levels and with their high revolution rates they can be better isolated than diesel engines. Diesel-electric propulsion systems are typically used for vessels with strict requirements for on board noise and vibration and UW radiated noise, e.g. cruise ships and research vessels [AQUO-SONIC, 2015].

Summarizing: effective machinery control solutions are available, but must be designed and implemented on a case-by-case basis, because noise transmission depends on detailed design of machines and their mounting system. Developing and implementing noise control solutions is most cost-effective when performed during the vessel's design stage. Retrofitting treatments always leads to additional costs, and some treatment approaches may not be possible because of space or other design restrictions [Spence & Fisher, 2017].

## 5.6 Noise mitigation in ship operation

*Maintenance*
Regular hull and propeller maintenance for improved fuel efficiency will implicitly reduce underwater radiated noise, since by decreasing the frictional resistance of hull and/or propeller the same vessel speed can be maintained with less propulsion power [AQUO-SONIC, 2015].

*Operational and logistic measures*
Furthermore, operational and logistic measures aimed at emission reduction through speed control, such as 'slow steaming' (§ 4.5.1) and 'just-in-time sailing' (§ 4.5.3) will also contribute to underwater noise reduction.

The ECHO programme (§ 5.3.6) carried out a first large scale study of the effects of 'slow steaming', which indicates that it can be effective for reducing shipping noise. Quoting from [MacGillivray et al, 2019]:
*During 2017, the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) program carried out a two-month voluntary vessel slowdown trial to determine whether slowing to 11 knots was an effective method for reducing underwater radiated vessel noise... The trial was carried out in Haro Strait, British Columbia, in critical habitat of endangered southern resident killer whales. Comparing measurements of vessels participating in the trial with measurements from control periods before and after the trial showed that slowing down was an effective method for reducing mean broadband SLs for five categories of piloted commercial vessels: containerships (11.5 dB), cruise vessels (10.5 dB), vehicle carriers (9.3 dB), tankers (6.1 dB), and bulkers (5.9 dB).*

*Monitoring tools*
Application of monitoring tools, as suggested for emission control (§ 4.5.2), and systems for real-time control of noise radiation could also offer an interesting solution, but these require further technical development [AQUO-SONIC, 2015].
Suggestions are:
- simultaneous control of engine rpm and propeller pitch, for optimum cavitation performance;
- propeller-induced cavitation monitoring systems, to guide selecting the optimum speed
- trim optimisation systems to reduce the required propulsion power.

# 6 Conclusion

## 6.1 Introduction

In this study, we investigate the options for reducing greenhouse gas (GHG) and pollutant emissions as well as underwater noise from commercial shipping, with a focus on the Belgian fleet.

## 6.2 Belgian fleet

In a survey (Chapter 2) of the Belgian fleet (452 ships) it was observed that dredgers form the largest group (24%), followed by crude oil tankers (17%). The largest size vessels are in this second group.

All vessels produce GHG and pollutant emissions as well as underwater radiated noise. Global analysis of the emissions of the Belgian shipping fleet indicates that the crude oil tankers are responsible for 33 to 38% of the total annual emission of $CO_2$, $NO_x$, $SO_x$ and PM of the Belgian fleet. Bulk carriers and LPG vessels follow with a contribution of 12 to 14% each.

In a follow-up study, the contribution of the underwater radiated noise of the different ship types to the underwater sound scape will be studied by means of modelled sound maps. In this report, a first tentative comparison of the contributions of the different ship types in the Belgian fleet was made by estimating their total underwater radiated noise power when sailing at design speed. This preliminary analysis suggests that the crude oil tankers potentially have the largest contribution to underwater radiated noise (42%), followed by the dredgers (16%), bulk carriers (11%) and container ships (10%). The model used for this analysis tentatively assumes that propeller-induced cavitation noise is the dominant noise source. Due to a lack of attention to underwater radiated noise in design and operation, details about the relative contributions of propeller and machinery to the underwater radiated noise of individual vessels are generally unknown.

## 6.3 Emission reduction

Chapter 4 provides an overview of the various options for emission reduction. Measures can be taken in several areas:

- Alternative energy carriers and power generation
  - Powertrains and alternative energy carriers go hand in hand. ZEV options are in development for maritime shipping. Studies show that for a wide variety of ship types, the use of biofuel ICE and Ammonia and $H_2$ in either ICE or FC have chances of success regarding economic profitability. Technologies including a significant size battery is much less favourable for the foreseeable future.
  - The applicability of different alternative energy carrier options will not be uniform for the Belgian fleet. Applicability depends on both technical conditions (such as ship and engine size) and ship operations (days at sea, sailing routes, average speed).
  - Switch to alternative energy carriers also opens up potential to reduce pollutant emissions such as $NO_x$, $SO_x$, and PM. On the other hand, an

  - alternative energy carrier can also create new emissions, for instance ammonia slip when using ammonia. This needs careful examination.
- Energy efficiency and aftertreatment
  - Improved energy efficiency is possible by reducing the friction of a vessel by applying solutions such as low-friction coating or by applying economies of scale.
  - Propulsion Improvement Devices (PID) can improve the flow around the hull or propeller and thus reduce fuel consumption. Propulsion can furthermore be assisted by innovations such as wind assist.
  - Emission control and aftertreatment such as scrubbers can reduce emissions of air pollutants
- Operations and logistics
  - Slow steaming is a common operating measure in shipping as a way to lower operating expenditures. The economic viability of slow steaming depends greatly on the market circumstances.
  - Monitoring tools can provide information on the functionality of the ship systems. By combining this information with route optimization software additional benefits can be reached by optimising ship speed and power usage.
  - Combining vessel data with availability schedules of port infrastructure can provide input for just-in-time sailing, avoiding waiting times in the port area and optimising fuel consumption.

## 6.4 Underwater radiated noise reduction

Chapter 5 provides an overview of the various options for underwater radiated noise reduction. Propeller-induced cavitation noise and propulsion engine machinery noise are generally the main sources of underwater radiated noise. Noise reduction can be achieved in design and operation of ships, as suggested in published general guidelines for noise reduction, such as [IMO MEPC, 2014; AQUO-SONIC, 2015].

Because of the large variety of ship designs within each ship type class, *underwater noise reduction in the design stage* must be done on a case-by-case basis. Developing and implementing noise control solutions is most cost effective and acoustically effective when performed during the vessel's design stage. Retrofitting vessels for reduced underwater noise is generally costly and not always possible. An important step towards achieving reduced underwater noise radiation from commercial vessels would be to set acoustic goals in the design stage of new vessels. Though presently there are no underwater noise goals set by regulatory bodies, classification societies already offer voluntary notations for commercial vessels that have mitigated underwater noise. Harmonization of the different quiet vessel certification approaches [Hannay et al, 2019] might facilitate a broader implementation of these notations.

Vessel speed control appears to offer a feasible *operational measure for underwater noise reduction* though, similar to noise control measures in ship design, there is no single solution that fits all ships. The optimum speed with respect to underwater radiated noise depends on the design of the ship's propulsion system and the possibilities to control this, via shaft rate and propeller pitch, which may vary significantly between ships.

Though more and more evidence of the effects of shipping noise on marine life is emerging [Rolland et al, 2012; Erbe et al, 2016; Kunc et al, 2016; Weilgart, 2018; Erbe et al, 2019], there are still significant knowledge gaps. More research is required toward better understanding of underwater sound generation from shipping and ways to manage and reduce resulting impacts on marine life.

## 6.5 Potential co-benefits of measures for reducing underwater radiated noise for energy efficiency and emission reduction

Ideally, measures taken to reduce emissions would also reduce underwater radiated noise of ships, but the link between the two has not yet been conclusively demonstrated, see for example Table 4.

Table 4 Conclusions from the ECHO Vessel Noise Correlations Study [MacGillivray et al, 2020] concerning the correlation of greenhouse gas and underwater sound emissions.

- "Greenhouse gas emissions exhibited a weak negative trend with underwater radiated noise for the Containers and Vehicle Carriers group in the 10–100 Hz and 100–1000 Hz bands. This means that for these vessel categories, vessels with a higher intensity of $CO_2$ emissions were slightly quieter.
- Greenhouse gas emissions exhibited a weak positive trend with underwater radiated noise for the Bulkers and Tankers category in the 100–1000 Hz and 1000–10000 Hz bands. This means that for these categories, vessels with higher $CO_2$ emissions intensity also had slightly higher underwater noise. Greenhouse gas emissions exhibited a weak negative trend with underwater radiated noise for the Containers and Vehicle Carriers group in the 10–100 Hz and 100–1000 Hz bands. This means that for these vessel categories, vessels with a higher intensity of $CO_2$ emissions were slightly quieter.
- When investigating $CO_2$ emissions against noise emissions using the EVDI ranking, the containers and vehicle carriers with a higher intensity of $CO_2$ emissions were slightly quieter, whereas for the bulkers and tankers category vessels with higher $CO_2$ emissions intensity also had slightly higher underwater noise. … In both instances, these trends were relatively weak, and do not indicate a conclusive correlation between EVDI and underwater noise emissions."

In general, all measures taken to reduce propulsion power and propeller thrust loading are beneficial for energy efficiency, emission reduction and underwater radiated noise reduction. Hence, wind assistance and optimized hull design and regular maintenance, aimed at reducing hull resistance, are all effective measures for reduced emissions and noise.

Design measures to reduce propeller cavitation will be effective for underwater radiated noise reduction. In particular, the hull and propeller need to be designed together, as a unit, such that a uniform wake field is created to reduce propeller cavitation. To some extent these will also increase energy efficiency, and reduce emissions. However, propeller designs optimized for cavitation reduction, as applied in naval and research vessels with stringent underwater noise limits, are generally not the most energy efficient.

Speed limits (‘slow steaming’) have a potential to be effective to control shipping underwater noise as well as energy efficiency and emission reduction, but different ship types have different optimum speeds and not all ship types can slow down to the same extent. Part 2 of this study (de Jong and Hulskotte, 2020) will further investigate the effectiveness of a slow steaming scenario by means of numerical simulations of commercial shipping at the North Sea.

# 7 References


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|---|---|
| Allen et al, 2012 | J.K. Allen, M.L. Peterson, G.V. Sharrard, D.L. Wright and S.K. Todd (2012) Radiated noise from commercial ships in the Gulf of Maine: Implications for whale/vessel collisions. J. Acoust. Soc. Am. 132 (3), EL229. |
| | Andrew, R. K., Howe, B. M., and Mercer, J. A. (2011). Long-time trends in ship traffic noise for four sites off the North American West Coast, J. Acoust. Soc. Am. 129, 642-651. |
| ANSI/ASA S12.64-2009 | ANSI/ASA S12.64-2009/Part 1, Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements. |
| AQUO-SONIC, 2015 | AQUO & SONIC EU FP7 projects (2015) Guidelines for regulation on UW noise from commercial shipping. Available from http://www.aquo.eu/downloads/AQUO-SONIC%20Guidelines_v4.3.pdf |
| Arveson & Vendittis, 2000 | P.T. Arveson and D.J. Vendittis (2000) Radiated noise characteristics of a modern cargo ship," J. Acoust. Soc. Am. 107, 118-129. |
| Audoly et al, 2017 | C. Audoly, T. Gaggero, E. Baudin, T. Folegot, E. Rizzuto, R.S. Mullor and P. Kellett (2017) Mitigation of underwater radiated noise related to shipping and its impact on marine life: a practical approach developed in the scope of aquo project, IEEE J. Ocean. Eng. 42 (2) 373-387. |
| Bahtiarian, 2019 | Mike Bahtiarian (2019) Quieting Ships to Protect the Marine Environment - Workshop Final Report. Acentech report #481, available to the public by emailing Transport Canada at TC.QuietShips-Naviressilencieux.TC@tc.gc.ca. |
| Basset et al, 2012 | C. Bassett, B. Polagye, M. Holt and J. Thomson (2012) A vessel noise budget for Admiralty Inlet, Puget Sound, Washington (USA), J. Acoust. Soc. Am. 132, 3706-3719. |
| Blake, 2017 | W.K. Blake (2017) Mechanics of Flow-Induced Sound and Vibration, 2nd ed., Elsevier Academic Press. |
| Bodogna, 2020 | Bodogna, G. (2020), Aerodynamics of wind-assisted ships Interaction effects on the aerodynamic performance of multiple wind-propulsion systems. |
| Bouman et al 2017 | Bouman, E.A., E. Lindstad, A.I. Rialland, A.H. Stromman (2017), State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. |
| Brown, 1976 | N.A. Brown (1976) Cavitation noise Problems and Solutions, in [Janssen (ed.), 1976]. |
| Brynolf et al, 2018 | Brynolf S., Taljegard M., Grahn M., Hansson J., (2018) Electrofuels for the transport sector: A review of production costs, Renewable and Sustainable Energy Reviews 81 1887-1905. |

| | |
|---|---|
| Buiten (ed.), 1986 | ISSA 1986: proceedings of the 2nd International Symposium on Shipboard Acoustics, organized by the TNO Institute of Applied Physics (TPD) on 7-9 October 1986 in The Hague, The Netherlands, edited by J. Buiten. |
| BV, 2018 | Bureau Veritas (2018) Underwater Radiated Noise (URN). Rule Note NR 614 DT R02 E. |
| Carlton, 2012 | J. Carlton (2012) Marine Propellers and Propulsion, Butterworth-Heinemann. |
| CE Delft et al, 2020 | CE Delft et al (2020), Fourth IMO GHG Study. |
| Chapman & Ellis, 1998 | D.M.F. Chapman & D.D. Ellis (1998) The elusive decibel: Thoughts on sonars and marine mammals, Canadian Acoustics 26(2), 29-31. |
| de Jong, 2002 | Christ de Jong (2002) “On the prediction of machinery noise transmission to underwater”. Proc. Undersea Defence Technology Europe, 18-20 June 2002, La Spezia. |
| de Jong & Hulskotte, 2020 | C.A.F. de Jong and J.H.J. Hulskotte (2020), Reduction of emissions and underwater radiated noise - Part 2. Draft TNO report. |
| DFO, 2017 | Department of Fisheries and Oceans, Canada (2017) Evaluation of the scientific evidence to inform the probability of effectiveness of mitigation measures in reducing shipping-related noise levels received by southern resident killer whales, Sci. Advis. Sec. Sci. Advis. Rep. 2017/041. |
| DGMO, 2019 | DGMO (2019), Renewable Energy – Recast to 2030 (RED II). https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii |
| DNV GL, 2018 | DNV GL (2018) DNV GL rules for classification and offshore standards. Silent (Pt. 6 Ch. 7 Sec. 6). |
| EC, 2008 | Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). |
| Erbe et al, 2016 | C. Erbe C.J. Reichmuth, K. Cunningham, K. Lucke and R. Dooling (2016) Communication masking in marine mammals: A review and research strategy. Marine Pollution Bulletin 103: 15-38. |
| Erbe et al, 2019 | Christine Erbe, Sarah Marley, Renée Schoeman, Joshua Smith, Leah Trigg and Clare Embling (2019) The Effects of Ship Noise on Marine Mammals—A Review. Front Mar Sci, 6, 606. |
| EU, 2017 | Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU. |
| Frisk, 2012 | Frisk, G (2012) Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends. Sci Rep 2, 437. |

| | |
|---|---|
| Gassmann et al, 2017 | M. Gassmann, L.B. Kindberg, S.M. Wiggins and J.A. Hildebrand (2017) Underwater Noise Comparison of Pre- and Post-retrofitted MAERSK G-Class Container Vessels, Scripps Institution of Oceanography, MPL-TM 616. |
| GLOMEEP, 2020 | Global maritime energy efficiency partnerships (2020) Speed Management https://glomeep.imo.org/technology/speed-management/ |
| Hannay et al, 2016 | D.E. Hannay, Z. Li and X. Mouy (2016) An automated real-time vessel sound measurement system for calculating monopole source levels using a modified version of ANSI/ASA S12.64-2009, Can. Acoust. 44, 166-167. |
| Hannay et al, 2019 | David E. Hannay, Heloise Frouin-Mouy, Jennifer L. Wladichuk, Federica Pace and Alexander O. MacGillivray (2019) A comparison of quiet ship certifications with the Enhancing Cetacean Habitat Observation (ECHO) ship noise database. (A) J. Acoust. Soc. Am. 146, 3062. |
| Hemmera, 2016 | Hemmera Envirochem Inc (2016) Vessel Quieting Design, Technology, and Maintenance Options for Potential Inclusion in EcoAction Program Enhancing Cetacean Habitat and Observation Program. |
| Heise et al, 2017 | Heise, K., Barrett-Lennard, L., Chapman, R., Dakin, T., Erbe, C., Hannay, D. E., Merchant, N., Pilkington, J., Thornton, S., Tollit, D. J., Vagle, S., Veirs, V., Vergara, V., Wood, J., Wright, B., and Yurk, H. (2017) Proposed metrics for the management of underwater noise for southern resident killer whales,” in Coastal Ocean Report Series, Report for the Coastal Ocean Research Institute (OceanWise, Vancouver, Canada). |
| IMO, 2015 | International Maritime Organization (2015), Third IMO GHG Study 2014. |
| IMO, 2020 | IMO (2020) Energy Efficiency measures. http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx |
| IMO MEPC, 2014 | International Maritime Organization, Marine Environment Protection Committee (2014) Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life. CIRC/MEPC/01/ 833. |
| IMO MEPC, 2018 | International Maritime Organization, Marine Environment Protection Committee (2018), Scientific Support for Underwater Noise Effects on Marine Species and the Importance of Mitigation (MEPC 73/INF.23). |
| IMO MEPC, 2019 | International Maritime Organization, Maritime Environment Protection Committee (2019):<br>- Quieting Ships to Protect the Marine Environment Workshop Summary Report Submitted by Canada (MEPC 74/17/2)<br>- Ship underwater radiated noise technical report and matrix. Submitted by Canada (MEPC 74/INF.28). |

| | |
|---|---|
| IMO MEPC, 2020 | International Maritime Organization, Maritime Environment Protection Committee (2020): Reduction of GHG emissions from ships. Wind propulsion solutions Submitted by Comoros. |
| ISO 18405, 2017 | International Organization for Standardization (2017) Underwater acoustics — Terminology, ISO 18405:2017. |
| ISO 17208-1, 2016 | International Organization for Standardization (2016) Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships — Part 1: Requirements for precision measurements in deep water used for comparison purposes, ISO 17208-1:2016. |
| ISO 17208-2, 2019 | Underwater acoustics — Quantities and procedures for description and measurement of underwater sound from ships — Part 2: Determination of source levels from deep water measurements, ISO 17208-2:2019. |
| ITTC, 2002 | International Towing Tank Committee (2002) Testing and Extrapolation Methods; Propulsion; Cavitation: Description of Cavitation Appearances. ITTC Recommended Procedures and Guidelines 7.5 – 02 03 - 03.2. |
| Jansen & de Jong, 2017 | Erwin Jansen and Christ de Jong (2017) Experimental Assessment of Underwater Acoustic Source Levels of Different Ship Types. IEEE Journal of Oceanic Engineering, Vol. 42, No. 2, 439-448. |
| Janssen (ed.), 1976 | ISSA 1976: proceedings of the 1st International Symposium on Shipboard Acoustics, organized by the TNO Institute of Applied Physics (TPD) on 6-10 September 1976 in Noordwijkerhout, edited by J. H. Janssen. |
| Joy et al, 2019 | Ruth Joy, Dominic Tollit, Jason Wood, Alexander MacGillivray, Zizheng Li, Krista Trounce and Orla Robinson (2019) Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales. Front. Mar. Sci. 6:344. doi: 10.3389/fmars.2019.00344. |
| Kaplan & Solomon, 2016 | M.B. Kaplan and S. Solomon (2016) A coming boom in commercial shipping? The potential for rapid growth of noise from commercial ships by 2030, Mar. Pol. 73, 119–121. |
| Kendrick & Terweij, 2019 | Andrew Kendrick and Rienk Terweij (2019) Ship underwater radiated noise. Vard Marine Inc. Report 368-000-01. prepared for the Innovation centre of transport Canada. Available from http://cismart.ca/wp-content/uploads/2018/08/386-000-01-URN-Report-Merged-Rev-3.pdf |
| Kuiper, 2010 | G. .Kuiper (2010) New developments and propeller design. 9th International Conference on Hydrodynamics October 11-15, 2010 Shanghai, China. |
| Kunc et al, 2016 | H.P. Kunc, K.E. McLaughlin and R. Schmidt (2016) Aquatic noise pollution: implications for individuals, populations, and ecosystems, Proc. Biol. Sci. 283 (1836) 20160839. |

| | |
|---|---|
| Leaper & Renilson, 2012 | R. Leaper and M. Renilson (2012]. A review of practical methods for reducing underwater noise pollution from large commercial vessels. International Journal of Maritime Engineering, Vol. 154, pp. A79-A88. |
| Leaper et al, 2014 | R. Leaper, M. Renilson and C. Ryan (2014) Reducing underwater noise from large commercial ships: current status and future directions. Journal of Ocean Technology, Vol. 9, No. 1, pp. 50-69. |
| Leaper, 2019 | Russel Leaper (2019) The Role of Slower Vessel Speeds in Reducing Greenhouse Gas Emissions, Underwater Noise and Collision Risk to Whales. Front. Mar. Sci. 6:505. |
| Lewandowski & Staaterman, 2020 | Jill Lewandowski and Erica Staaterman (2020) International management of underwater noise: Transforming conflict into effective action. J. Acoust. Soc. Am. 147 (5), 3160-3168. |
| Lloyd’s Register, 2018 | Lloyd’s Register (2018) ShipRight. Additional Design and Construction Procedure for the Determination of a Vessel’s Underwater Radiated Noise. |
| Ma, 2014 | Ma Shuo (2014) When will be the end of “slow-steaming”?. Public lecture at Nottingham Trent University. http://www.cee.ntu.edu.sg/NewsnEvents/EPres/Documents/Sem30Sep14/Slowsteaming%20-%20NTU%202014.pdf |
| MacGillivray et al, 2019 | Alexander MacGillivray, Zizheng Li, David Hannay, Krista Trounce and Orla Robinson (2019) Slowing deep-sea commercial vessels reduces underwater radiated noise. J. Acoust. Soc. Am. 146 (1), 340-351. |
| MacGillivray et al, 2020 | MacGillivray, A.O., L. Ainsworth, J. Zhao, H. Frouin-Mouy, J. Dolman, and M. Bahtiarian. 2020. ECHO Vessel Noise Correlations Study: Final Report. Document 02025, Version 2.1. Technical report by JASCO Applied Sciences, ERM, and Acentech for Vancouver Fraser Port Authority ECHO Program. |
| Marin, 2019 | Marin (2019), Sea Shipping Emissions 2017: Netherlands Continental Shelf, 12 Mile Zone and Port Areas. |
| McDonald et al, 2006 | McDonald, M. A., Hildebrand, J. A., and Wiggins, S. M. (2006). Increases in deep ocean ambient noise in the Northwest Pacific west of San Nicolas Island, California, J. Acoust. Soc. Am. 120, 711-717. |
| McKenna et al, 2012 | M.F. McKenna, D. Ross, S.M. Wiggins and J.A. Hildebrand (2012) Underwater radiated noise from modern commercial ships, J. Acoust. Soc. Am. 131, 92-103. |
| McKenna et al, 2013 | M.F. McKenna, S.M. Wiggins and J.A. Hildebrand (2013) Relationship between container ship underwater noise levels and ship design, operational and oceanographic conditions,” Sci. Rep. 3, 1760. |
| Merchant, 2019 | N. Merchant (2019) Underwater noise abatement: economic factors and policy options. Environ Sci Pol 92. 116-123. |

| | |
|---|---|
| Miksis-Olds & Nichols, 2016 | J.L. Miksis-Olds, S.M. Nichols (2016) Is low frequency ocean sound increasing globally? J. Acoust. Soc. Am. 139 (1), 501-511. |
| Mitson, 1995 | R.B. Mitson (1995) Underwater noise of research vessels - Review and Recommendations. International Council for the Exploration of the Sea (ICES). Cooperative Research Report No. 209. |
| NATO STANAG 1136 | NATO (1995) Standards for Use When Measuring and Reporting Radiated Noise Characteristics of Surface Ships, Submarines, Helicopters, etc. in Relation to Sonar Detection and Torpedo Acquisition Risk. STANAG 1136. |
| Parker et al, 2015 | Sophia Parker, Carlo Raucci, Tristan Smith, and Ludovic Laffineur (2015) Understanding the Energy Efficiency Operational Indicator: an empirical analysis of ships from the Belgian Shipowners' Association. |
| Prins et al, 2016 | H.J. Prins, M.B. Flikkema, J. Bosschers, Y. Koldenhof, C.A.F. de Jong, C. Pestelli, M. Hyensjö (2016) Suppression of underwater noise induced by cavitation: SONIC, Trans.Res. Procedia 14 (2016) 2668-2677. |
| RBSA, 2017 | Royal Belgian Shipowners Association (2017) Economic Impact Study Belgian Shipping Cluster – Update 2017. |
| Rolland et al, 2012 | R.M. Rolland, S.E. Parks, K.E. Hunt, M. Castellote, P.J. Corkeron, D.P. Nowacek and S.D. Kraus (2012) Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society of London B: Biological Sciences, 279(1737), 2363-2368. |
| Ross, 1976 | D. Ross (1976) Mechanics of Underwater Noise, Peninsula Publishing, Los Altos, CA. |
| Sertlek et al, 2019 | Hüseyin Özkan Sertlek, Hans Slabbekoorn, Carel ten Cate and Michael A. Ainslie (2019) Source specific sound mapping: Spatial, temporal and spectral distribution of sound in the Dutch North Sea. Environmental Pollution 247, 1143-1157. |
| Simard et al, 2016 | Y. Simard, N. Roy, C. Gervaise and S. Giard (2016) Analysis and modeling of 255 source levels of merchant ships from an acoustic observatory along St. Lawrence Seaway," J. Acoust. Soc. Am. 140, 2002-2018. |
| Simmonds et al, 2014 | Mark Peter Simmonds, Sarah J. Dolman, Michael Jasny, E.C.M. Parsons, Lind Weilgart, Andrew J. Wright and Russell Leaper (2014) Not so easy listening: making sense of the noise about acoustic pollution. Journal of Ocean Technology 9(1), 71-90. |
| Slabbekoorn et al. (eds.), 2018 | Hans Slabbekoorn, Robert J. Dooling, Arthur N. Popper and Richard R. Fay (eds.), (2018), Effects of Anthropogenic Noise on Animals, Springer Handbook of Auditory Research, Volume 66. |

| | |
|---|---|
| Smith et al, 2013 | Tristan Smith, Eoin O'Keeffe, Lucy Aldous and Paolo Agnolucci (2013) Assessment of Shipping's Efficiency Using Satellite AIS data. UCL Energy Institute, Royal Belgian Shipowners' Association. |
| Southall, 2005 | Southall, B.L. (2005). Shipping Noise and Marine Mammals: a Forum for Science, Management, and Technology. Final Report of the National Oceanic and Atmospheric Administration (NOAA) International Symposium. U.S. NOAA Fisheries, Arlington, Virginia, May 18–19, 2004. |
| Southall, & Scholik-Schlomer, 2008 | Southall, B.L. and A. Scholik-Schlomer (2008). Final report of the NOAA International Conference: "Potential Application of Vessel-Quieting Technology on Large Commercial Vessels," 1–2 May 2007, Silver Spring, MD, USA. |
| Southall et al, 2018 | B. Southall, L. Hatch, A.R. Scholik-Schlomer, T. Bergmann, M. Jasny, K. Metcalf, L.S. Weilgart, A.J. Wright and M.E. Perera, (2018). Reducing noise from large commercial ships: Progress and partnerships, in Proceedings of the Marine Safety and Security Council—Coast Guard Journal of Safety and Security at Sea, Vol. 1, pp. 58–65. |
| Spence & Fischer, 2016 | J. Spence, R. Fischer (2016) Underwater noise from Ships–causes and general approaches to noise control, in: 23rd International Congress on Sound and Vibration. |
| TC, 2019 | Transport Canada (2019) The CISMaRT/Transport Canada Workshop on Ship Noise Mitigation Technologies for a Quieter Ocean. |
| TNO 2019 | TNO (2019), TNO Kennisinbreng Mobiliteit voor Klimaat- en Energieverkenning (KEV) 2019. Report TNO 2019 P12134. |
| TNO 2020 | TNO (2020), Green Maritime Methanol Operation aspects and the fuel supply chain. Report TNO 220 R11105. |
| TNO, Marin and TU Delft 2017 | Vision Paper on automated barging; Settings sails towards the future of inland navigation. |
| TU Delft, EUR, TNO 2018 | "Autonomous Ships in the Port of Rotterdam". Exploration of Perspectives and Potential. |
| Urick, 1975 | R.J. Urick (1975) Principles of underwater sound, McGraw-Hill, New York. |
| Vakili et al, 2020 | S.V. Vakili, A.I. Ölcer and F. Ballini (2020) The development of a policy framework to mitigate underwater noise pollution from commercial vessels. Marine Policy 118, 104004. |
| Van den Berg, 2018 | Low carbon shipping A decision support tool for the implementation of $CO_2$ reducing measures |
| Veirs et al, 2016 | S. Veirs, V. Veirs and J.D. Wood (2016) Ship noise extends to frequencies used for echolocation by endangered killer whales, PeerJ 4 e1657. |
| Waterborne 2020 | Partnership proposal for Zero-emission waterborne transport (https://www.waterborne.eu/images/documents/200527_Zero-Emission_Waterborne_Transport_Proposal_Final_Version_Spread.pdf) |

| | |
|---|---|
| Weilgart, 2018 | Weilgart, L. 2018. The impact of ocean noise pollution on fish and invertebrates. Report for OceanCare, Switzerland. |
| Williams et al, 2019 | R. Williams, S. Veirs, V. Veirs, E. Ashe and N. Mastick (2019) Approaches to reduce noise from ships operating in important killer whale habitats (2018) Marine Pollution Bulletin 139, 459-469. |
| Wright, 2008 | Wright, A.J. (ed) 2008. International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21$^{st}$-24th April 2008. Okeanos – Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. |

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# 9 Signature

The Hague, November 2020

TNO
Acoustics & Sonar

Drs. C. M. Ort
Research manager

Dr.Ir. C.A.F. de Jong
Author

# A Belgian fleet data

Table A.1 Overview of the database parameters provided from a database search for ships of Belgian owners by Clarkson Research Services Limited.

| |
|---|
| IMO Number |
| MMSI (Maritime Mobile Service Identity) |
| Name |
| Owner |
| Group Owner |
| Owner Nationality/Region |
| Flag State |
| Classification Society |
| type |
| year built |
| GT |
| Dwt |
| NT |
| TEU |
| Service Speed (knots) |
| Engine Derived Total Main Engine Mechanical kW |
| Engine Derived Total Mechanical Propulsion (kW) |
| Main Consumption at Service Speed (tpd) |
| Power Type |
| Main Engine Model |
| Main Engine Model Series |
| Main Engine Model Designer |
| Main Engine Model Designer group |
| Main Engine Fuel Type |
| Main Engine 1 Major Designer Company |
| Main Engine 1 Manufacturer Company |
| Main Engine 1 Model |
| Main Engine 1 Equipment Type |
| Main Engine 1 Rpm |
| Main Bunker Capacity ($m^3$) |
| Main Bunker Fuel Type |

Table A.2 Main characteristics of Belgian ships per ship type, with propulsion types D2S = Diesel 2-stroke, D4S = Diesel 4-stroke, DE = Diesel-Electric, ST = steam turbine and NP = non-propelled

| Type | nr | Design speed (kn) | | | Gross tonnage GT | | | Length (m) | | | propulsion |
|---|---|---|---|---|---|---|---|---|---|---|---|
| total | **452** | min | avg | max | min | avg | max | min | avg | max | |
| Container ships | 23 | 17.5 | 22.0 | 25.0 | 6,910 | 34,073 | 58,289 | 114 | 212 | 267 | 22 D2S, 1 D4S |
| General Cargo | 10 | 8.0 | 10.4 | 12.0 | 141 | 878 | 2,061 | 24 | 46 | 70 | 2 D2S, 8 D4S |
| Bulkers | 61 | 12.0 | 14.6 | 16.1 | 13,691 | 63,483 | 108,130 | 150 | 268 | 342 | 60 D2S,1 D4S |
| Reefers | 5 | 21.5 | 22.7 | 23.0 | 14,061 | 14,061 | 14,061 | 151 | 151 | 151 | 5 D2S |
| Multi-Purpose | 3 | 10.5 | 11.5 | 12.5 | 2,061 | 2,503 | 2,999 | 70 | 76 | 82 | 3 D4S |
| Roll-on/roll-off | 28 | 15.5 | 18.2 | 21.7 | 11,854 | 32,743 | 74,273 | 141 | 206 | 294 | 7 D2S, 21 D4S |
| Crude Tankers | 73 | 14.5 | 15.6 | 16.5 | 60,178 | 128,880 | 234,006 | 271 | 362 | 466 | 73 D2S |
| Chemical Tankers | 7 | 14.8 | 15.0 | 15.5 | 7,776 | 14,882 | 19,968 | 119 | 153 | 174 | 6 D2S, 1 D4S |
| Product Tankers | 12 | 11.0 | 13.5 | 15.1 | 400 | 21,944 | 94,729 | 36 | 145 | 324 | 5 D2S, 7 D4S |
| LNG | 5 | 19.1 | 19.2 | 19.5 | 93,719 | 96,902 | 102,777 | 323 | 327 | 335 | 5 ST |
| LPG | 33 | 13.6 | 15.4 | 17.4 | 3,419 | 20,330 | 47,306 | 86 | 164 | 246 | 32 D2S, 1 D4S |
| Oth Non Cargo | 24 | 8.0 | 11.5 | 18.0 | 106 | 439 | 2,462 | 21 | 35 | 75 | 19 D4S, 5 DE |
| Tugs | 33 | 9.2 | 12.6 | 25.4 | 106 | 328 | 578 | 21 | 33 | 42 | 3 D2S, 30 D4S |
| Dredgers | 110 | 7.0 | 13.1 | 18.5 | 110 | 7,556 | 46,373 | 22 | 101 | 244 | 2 D2S, 54 D4S 32 DE, 22 NP |
| Offshore | 25 | 8.0 | 13.0 | 17.0 | 106 | 25,628 | 236,638 | 21 | 114 | 468 | 2 D2S, 15 D4S 5 DE, 3 NP |

- Length between particulars (Lpp) was not provided in the database search. Therefore, length was estimated from the gross tonnage based on the general regression formula $L \approx (20 \times \mathrm{GT})^{0.4}$ (fitted to a subset of the data for which the length could be retrieved from AIS records).
- ‘Non-propelled’ (NP) vessels in the database are typically backhoe or cutter dredger platforms and floating storage, production and offloading (FSPO) platforms for offshore oil extraction. These rely on tugs for transit between locations.

# B Plan voor duurzame scheepvaart

**PLAN VOOR DUURZAME SCHEEPVAART**

4 juli 2018

PHILIPPE DE BACKER

Service public fédéral
Mobilité et Transports

Union
Royale des
Armateurs Belges

## Partnerschapsovereenkomst tussen:

- De Koninklijke Belgische Redersvereniging, vertegenwoordigd door de heer Ludwig Criel, voorzitter KBRV en de heer Wilfried Lemmens, directeur
- Directoraat-generaal Scheepvaart, FOD Mobiliteit en Vervoer, vertegenwoordigd door de heer Eugeen Van Craeyvelt, directeur-generaal
- De Staatssecretaris bevoegd voor Noordzee, de heer Philippe De Backer

De scheepvaart is van groot belang voor de wereldwijde handel en onmisbaar voor de welvaart in België. Jaarlijks varen er gemiddeld 150.000 schepen door het Belgische deel van de Noordzee. Het betreft zowel het transitverkeer van het zuiden naar het noorden en omgekeerd, als het verkeer van en naar de Belgische havens dat aansluit op het wereldwijd koopvaardijverkeer.

De handelsvloot die onder Belgische vlag vaart, vertegenwoordigt een brutotonnenmaat (GT) van meer dan 5,4 miljoen en een draagvermogen (DWT) van meer dan 7,8 miljoen, waarmee ze tot de top 25 van de IMO lidstaten behoort.
De door België gecontroleerde vloot is goed voor plaats 18 van zeevarende naties. De vloot van de Belgische reders is anderhalf keer meer gegroeid dan de wereldvloot. Aan boord van de Belgische zeeschepen werken dagelijks meer dan 5.500 mensen.

België is een maritieme natie en dit al meer dan 180 jaar. Als lid van de Council van IMO verdedigen wij de visie van duurzame scheepvaart, eerlijke concurrentie en gelijk speelveld. Om deze voortrekkersrol te kunnen blijven spelen is het nodig dat we blijven inzetten op vernieuwing en modernisering.

Dit partnerschapsakkoord stelt maatregelen voor op volgende vlakken:
- Administratieve vereenvoudiging door digitalisering
- Verbetering en vereenvoudiging door wetgevende initiatieven
- Creëren van een gelijk speelveld
- Internationale samenwerking
- Vergroening van de scheepvaart

## I. Administratieve vereenvoudiging door digitalisering

**(1) Digitalisering certificaten**

Het gebruik van elektronische certificaten aan boord van schepen is sinds enkele jaren goedgekeurd binnen IMO. Denemarken is als eerste land begonnen met het afleveren van digitale certificaten en uit de resultaten blijkt dat de Deense vloot hier geen hinder van heeft ondervonden, wel integendeel.

Er zijn vele voordelen gekoppeld aan het gebruik van elektronische certificaten.

Als eerste belangrijke punt kan België zich door dit project profileren als een vernieuwende en vooruitstrevende vlag die mee is met de laatste technologieën. Dit kan de reputatie en aantrekkingskracht van de Belgische vlag enkel ten goede komen.

Er gaat ook een groot gebruiksgemak gepaard met het afleveren van elektronische certificaten. De certificaten worden nu op veiligheidspapier afgedrukt, getekend en opgestuurd naar de rederij. Dit alles neem tijd in beslag. De scheepvaartsector is een hoogtechnologische sector waar snelheid van groot belang is. Door het gebruik maken van elektronische certificaten worden wachttijden door het versturen van de papieren certificaten per post vermeden en heeft de rederij meteen de juiste certificaten aan boord zonder wachttijden.

Door ook de aanvraag elektronisch te laten verkopen, via elektronische toepassingen van DG Scheepvaart, kan de reder nog sneller en eenvoudiger het hele certificatieproces opvolgen.
Verder kan het gehele proces volledig gestroomlijnd worden. Zo kan voor de betaling van de retributie voor een certificaat of meerdere certificaten het totale bedrag van de retributie automatisch berekend worden en zou het systeem meteen ook een factuur kunnen verzenden naar de rederij. Ook voor de rederij levert dit voordelen daar zij voor meerdere schepen tegelijk een aanvraag kunnen doen, verwarring omtrent bedragen van retributies wordt vermeden en ze een onmiddellijk een bewijsstuk hebben voor de boekhouding.

Tot slot laten elektronische certificaten een betere en accuratere controle toe. Zo kan voor een schip dat niet meer aan de voorwaarden voldoet, een elektronisch certificaat onmiddellijk ingetrokken worden. Buitenlandse havenstaatcontroles die toezien op de veiligheid van schepen kunnen ook eenvoudiger en sneller controleren of alle certificaten voor een schip werden afgeleverd én nog geldig zijn en dit door gebruik te maken van het nummer en datum van het certificaat en het IMO nummer van het schip. Fraude met certificaten kan op deze manier ook volledig worden uitgesloten.

**Actie:**
DG Scheepvaart zal het gebruik van elektronische certificaten samen met de KBRV verder uitwerken en zorgen voor de nodige wettelijk omkadering en een functionele analyse op het gebied van ICT toepassing laten uitvoeren.
Naast het systeem van elektronische certificaten zal DG Scheepvaart in overleg met KBRV de mogelijkheden onderzoeken om elektronische logboeken te gebruiken in overeenstemming met de richtsnoeren die momenteel worden besproken binnen de Internationale Maritieme Organisatie.

(2) **Elektronische verzending van arbeidsovereenkomsten (E-crew)**

Art. 37 van de wet van 3 juni 2007 houdende diverse arbeidsbepalingen bepaalt dat Bij het sluiten van de arbeidsovereenkomst zal
- een exemplaar overhandigd worden aan de zeevarende,
- een ander exemplaar zich aan boord van het zeeschip dienen te bevinden waar de zeevarende het op elk ogenblik moet kunnen inkijken
- een derde exemplaar onverwijld moeten overgezonden worden aan de met de scheepvaartcontrole belaste ambtenaar die daartoe is aangesteld van de thuishaven van het zeeschip

Met het project E-crew zal het overmaken van de arbeidsovereenkomst voor zeevarende op elektronische wijze kunnen overgemaakt worden aan hogergenoemde met de scheepvaartcontrole belaste ambtenaar.
De elektronische verzending van arbeidsovereenkomsten voor zeevarende biedt opnieuw vele voordelen: opnieuw worden administratieve lasten verlaagd voor de klant en heeft de bevoegde ambtenaar onmiddellijk de juiste gegevens ter zijner beschikking.

Op deze manier kan automatisch gecontroleerd worden of de minimumbezetting en de kwalificaties van de bemanningsleden, zoals opgenomen in het bemanningsplan opgesteld en goedgekeurd overeenkomstig art. 91 van het KB van 20 juli 1973 houdende zeevaartinspectiereglement gerespecteerd werden.

**Actie:**
DG Scheepvaart zal een functionele analyse uitvoeren om dit project in de praktijk uit te rollen.

(3) **Belgian Maritime Single Window (BMSW)**

Richtlijn 2010/65/EU verplicht de lidstaten om een maritiem single window te hebben zodat deze meldingen elektronisch en eenmalig gebeuren. Op grond van deze richtlijn worden 2 categorieën van meldingen aangemerkt als verplicht te melden, nl. de meldingen die voortkomen uit rechtshandelingen van de Europese Unie en deze die voortkomen uit nationale wetgeving.

Concreet worden in België gegevens van zowel de federale en Vlaamse overheid als van de havensystemen met elkaar gelinkt via de uitbouw van bestaande structuren en het CBS en FSB systeem. Een aantal meldingen hierin nog niet raadpleegbaar.

Europa werkt momenteel aan een herziening van de richtlijnen gelet op de vele moeilijkheden waarmee de verschillende lidstaten worstelen bij de uitvoering ervan, kan een Europees Maritime Single Window een mogelijke verder te exploreren piste zijn.

Als vooruitstrevende maritieme natie wenst België geen tijd te verliezen en reeds intern na te gaan op welke manier de uitwisseling van bestaande als nieuwe gegevensstromen sneller en efficiënter kan opgezet worden via een vlot toegankelijk platform en dit met de nodige aandacht voor de veiligheid van de gegevens en bescherming van de privacy.

Hierbij kan ook de piste van de publiek-private samenwerking onderzocht worden.

**Actie:**
Kabinet De Backer zal samen met DG Scheepvaart alle betrokken federale instanties rond de tafel brengen en een behoefte analyse en stappenplan opstellen om het BMSW verder uit te bouwen en de nodige voorbereidingen te treffen om te kunnen voldoen aan de voorschriften van de nieuwe Europese regelgeving. Met de bevoegde Vlaamse minister(s) zal bekeken worden om hieromtrent een gezamenlijk project op te zetten.

## II. Verbetering en vereenvoudiging via wetgevende initiatieven

**(4) Ratificatie Verdrag aangaande de identiteitsdocumenten van zeevarenden[1] (ILO 185)**

Het in- en ontschepen van bemanning van vreemde schepen in Belgische havens of van Belgische schepen in vreemde havens brengt de nodige formaliteiten met zich mee waaronder het beschikken over een geldig visum.

**(1)** [1] Seafarers'Identity Document Convention

De ratificatie van dit verdrag faciliteert en vereenvoudigt bemanningswissels tussen ratificerende landen gezien deze landen zich er onderling toe verbinden om zeevarenden binnen de kortst mogelijke tijd, toegang te geven tot hun grondgebied voor zover deze beschikt over een geldig identiteitsbewijs vergezeld van een paspoort en dit voor
- inschepen op een schip of overgaan naar een ander schip;
- transit om in te schepen op hun schip in een ander land of voor repatriëring of voor redenen toegelaten door de overheid van dat land.

**Actie:**
Kabinet De Backer en DG Scheepvaart zullen in overleg met de bevoegde administraties van Werk en Binnenlandse Zaken, de nodige stappen ondernemen om dit verdrag te ratificeren.

**(5) Ratificatie van het protocol tot bestrijding van wederrechtelijke gedragingen gericht tegen het de veiligheid van de zeevaart (SUA-protocol)[2]**

Veiligheid is een prioriteit voor deze regering en dit zowel op land als op water.

Belgie is reeds lid van het SUA Verdrag : Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation (1971), die een aantal gedragingen zoals het overnemen van een schip met geweld, geweld tegen personen op een schip die de veiligheid van het schip in het gedrang brengen, vernietiging of beschadiging van het schip of de lading of het verspreiden van valse informatie zodat het schip niet meer veilig kan varen, ... strafbaar stelt.

Het SUA protocol uit 2005 stelt bijkomende daden strafbaar waaronder het gebruik van schepen om biologische, chemische of nucleaire wapens te vervoeren of het lozen van olie, radioactieve materialen, gas of andere schadelijke stoffen in dergelijke hoeveelheden dat zij de dood, of ernstige verwondingen of schade tot gevolg hebben. Ook het gebruik van deze wapens of schadelijke stoffen tegen zeeschepen wordt uitdrukkelijk verboden.

Dit protocol werd gesloten om terrorisme tegen schepen te voorkomen en te onderdrukken en om de veiligheid aan boord en aan land te verhogen en de risico's voor passagiers, bemanning , havenpersoneel en schepen te beperken . Bovendien worden extra mogelijkheden geboden om vb. personen uit te leveren of de lading van schepen op volle zee reeds te gaan controleren. Dit kadert volledig in de scope van de nieuwe cel maritieme beveiliging die recent werd opgericht met het oog op de beveiliging van onze Belgische schepen en wateren, waardoor de ratificatie noodzakelijk geacht wordt.

Door de ratificatie van dit protocol zal België zijn reputatie van maritieme natie nogmaals aantonen doordat we nu de nodige stappen zetten om in 2021 het eerste land te zijn dat alle IMO-verdragen geïmplementeerd zal hebben.

**Actie:**
Kabinet De Backer en DG Scheepvaart zullen het nodige doen om een snelle ratificatie van het SUA protocol te bewerkstelligen.

**(2)** [2] Suppression of Unlawful Acts Against the Safety of Maritime Navigation

**(6) Belgisch Scheepvaartwetboek (BSW)**

In 2007 werd de Koninklijk Commissie voor de herziening van het maritiem recht opgericht. Meer dan 10 jaar en 11 blauwboeken later werd een ontwerp van Belgisch Scheepvaartwetboek op 22 december 2017 goedgekeurd op de ministerraad.

Om België het wetboek te geven dat aangepast is aan de noden van het moderne scheepvaartlandschap, is het belangrijk dat dit wetgevend proces afgerond wordt.

**Actie:**
Kabinet De Backer verbindt zich ertoe het Belgisch Scheepvaartwetboek nog dit jaar in het parlement in te dienen.

## III. Creëren van een gelijk speelveld

**(7) Versterken van de havenstaatcontroles (PSC) op schepen in Belgische havens**

De controles aan boord van schepen wordt opgelegd door de Europese richtlijn 2009/16/EG (KB 22 december 2010) en houden verband met de internationale maritieme bepalingen rond:
- veiligheid van schip en opvarenden;
- beveiliging van het schip;
- bescherming van het mariene milieu;
- leven en werkomstandigheden aan boord.

Met het oog op een effectieve en eenduidige toepassing van de havenstaatcontrole, hebben de Europese landen, IJsland, Noorwegen, Canada en Rusland gemeenschappelijke afspraken gemaakt en vastgelegd in de Paris MOU. Deze afspraken hebben o.a. betrekking op het minimum aantal te controleren schepenen, het risicomodel waarop deze geselecteerd worden en bepaalde specifieke vereisten.

De dienst havenstaatcontrole bestaat uit 11 personen waaronder 9 inspecteurs die samen jaarlijks een 1000-tal schepen controleert.

De versterking van de controles zal naast preventieve acties, zoals het sensibiliseren en informeren van zeevarenden over hun rechten en plichten, ook repressieve acties omvatten.

Zo zal bij controles aan boord een PV opgesteld worden wanneer vastgesteld wordt dat:
- de MLC wetgeving niet gerespecteerd wordt;
- tijdelijk opgelegde maatregelen geen effect sorteren;
- bewust inbreuken worden gepleegd om economisch voordeel te bekomen;
- herhaaldelijk nalatigheden worden vastgesteld.

**Actie:**
Kabinet De Backer zal samen met DG Scheepvaart het toepassingsgebied van de wet administratieve geldboetes uitbreiden met overtredingen van de MLC-wet. Om inbreuken vlot en eenvormig te kunnen vaststellen zal ten behoeve van de inspecteurs een basisvragenlijst opgesteld en guidelines uitgewerkt worden.

## IV. Bevorderen van de internationale samenwerking

**(8) Afsluiten van bilaterale akkoorden**

In maart 2017 ontving België het tweevoudig verzoek van Panama om een bilateraal akkoord te sluiten betreffende de wederzijdse erkenning van de opleiding en diplomering van zeevarenden en om Panama voor te dragen bij Europa met het oog op een Europese erkenning.

Door het sluiten van het bilateraal akkoord krijgen de Panamese zeevarenden dezelfde toegang tot het beroep op Belgische schepen en dit onder dezelfde loon- en arbeidsvoorwaarden als de Belgische zeevarenden en omgekeerd. De bevoegde Belgische diensten dienen hiertoe een audit uit te voeren bij de Panamese zeevaartscholen.

Overeenkomstig de Europese richtlijn 2012/35/EU , kan België Panama voordragen bij Europa om alzo een Europese erkenning van de opleidings- en diplomeringssystemen te bekomen. Op die manier kan Panama op de white list van zeevarenden van de EU komen. Om een dergelijke erkenning te bekomen zal een audit dienen te gebeuren door EMSA.

Panama is de grootste vlaggenstaat en een vermelding op de white list komt hun reputatie ten goede. Het feit dat hiervoor België aangezocht werd benadrukt nogmaals de hoge kwaliteit van onze vlag en bevoegde diensten.

**Actie:** Kabinet de Backer en DG Scheepvaart zullen de nodige audits uitvoeren en aanvragen met het oog op sluiten van een bilateraal akkoord en het bekomen van de Europese erkenning.

## V. Vergroening van de scheepvaart

**(9) High Ambition Coalition voor scheepvaart**

België heeft samen met de Marshall Islands en de Solomon Islands een leidende rol binnen de HAC voor scheepvaart om zo te streven naar een hoog ambitieniveau en strategie om de uitstoot van broeikasgassen door de scheepvaartsector te verminderen.

Op 13 april 2018 werd op MEPC72 een akkoord gesloten om de uitstoot van broeikasgassen met 50% zal verminderd worden ten opzichte van 2008. Deze initiële strategie zal in 2023 herzien worden waarbij rekening zal gehouden worden met de technologische ontwikkelingen en de resultaten van de data collectie die binnen IMO werd opgestart.

**Actie:**
Kabinet De Backer en DG Scheepvaart zullen blijven streven naar een verdere vergroening en decarbonisatie van de scheepvaart. Als lid van de Raad van de IMO blijft België een voortrekkersrol spelen in dit debat. De KBRV zal door middel van de denktank de nodige input geven om dit debat op technologisch en operationeel vlak te ondersteunen.

(10) **Kwaliteit van scheepsbrandstoffen**

Sinds 1 januari 2015 is de Noordzee een gebied waarbij het zwavelgehalte in de brandstof beperkt wordt tot maximaal 0,1 %, tenzij er systemen worden gebruikt die de zwavel uit de uitlaatgassen filteren alvorens deze worden geloosd. DG Scheepvaart is bevoegd om de controles uit te voeren op de gebruikte brandstoffen. Voor de reders is het evenwel van groot belang om ook de brandstoffen te krijgen die voldoen aan de vereiste standaarden.

Binnen MARPOL wordt enkel een verwijzing opgenomen naar de ISO standaarden voor scheepsbrandstoffen. Deze standaarden bevatten echter niet voor alle stoffen relevante parameters. Echter kan een bepaalde hoeveelheid van schadelijke stoffen in de scheepsbrandstoffen defecten veroorzaken aan de motoren van de schepen. Naast de schade aan de motor, moet de reder de getankte brandstof debunkeren en nieuwe brandstof aankopen wat een ernstig financieel nadeel is.

Op initiatief van de KBRV is er een werkgroep opgericht waarbij de reders, administraties en haven uit Nederland, Duitsland en België betrokken zijn om een gezamenlijke aanpak van deze problematiek uit te werken. Ook andere stakeholders zoals de bunkerleveranciers en ISO zijn betrokken in deze werkgroep.

**Actie:**
Kabinet De Backer en DG Scheepvaart zullen samen met de bevoegde administraties onderzoeken hoe een controlesysteem op scheepsbrandstoffen die in België worden geleverd uitgewerkt kan worden. DG Scheepvaart en de KBRV zullen samenwerken binnen de werkgroep voor scheepsbrandstoffen en eventuele resultaten van deze werkgroep op de agenda van IMO plaatsen.

Dit partnerschapsakkoord zal jaarlijks geëvalueerd worden .

Op gemaakt te Antwerpen op 4 juli 2018.

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