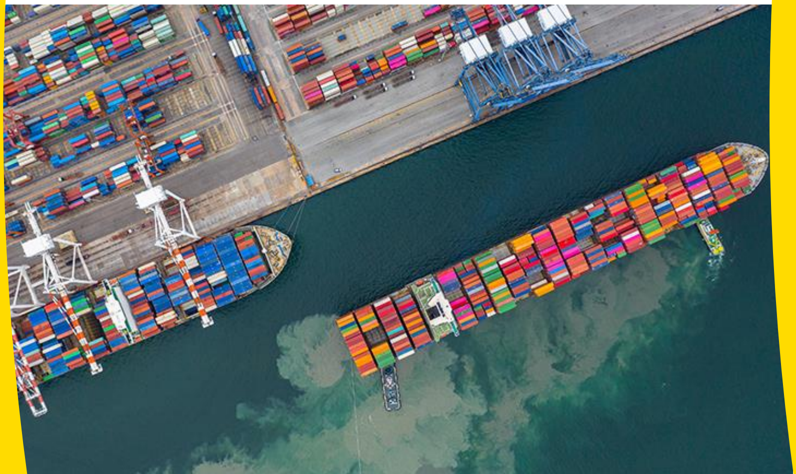
Blue Speeds for shipping

Economic analysis and legal framework to achieve environmental benefits



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Blue Speeds for shipping

Economic analysis and legal framework to achieve environmental benefits

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Content

Summary

The maritime shipping sector produces continuous sounds, covering a wide range of frequencies and is the largest contributor of low frequency anthropogenic underwater radiated noise (URN) to the marine environment. URN can have negative impacts on both marine habitats and marine life.

Currently, there are maximum noise level limits in place to prevent adverse impacts on human health from airborne noise. There are, however, no mandatory limits for noise levels to prevent adverse effects of URN from ships on the marine environment.

There are different technical and operational options available to reduce URN from the shipping sector. Ideally, URN is considered when designing new ships, but so far this is seldomly the case, except for navy, cruise and research vessels for which low sound and vibration levels play an important role in their operation. Technical retrofit measures are available too, but reducing an existing ship's URN is more difficult and expensive than consideration at the design stage. For existing ships, the reduction of speed is a very effective measure to reduce URN over the entire frequency range.

The focus of this report is on 'Blue Speeds' - ship speed levels that protect the marine environment from the negative impact of URN and that are associated with co-benefits for marine life and humans by reducing the hazard of ship strikes to whales, GHG emissions and air pollution.

There are various policy options to ensure that ships engaged in EU-related maritime transport sail at Blue Speeds. This report analyses these options and proposes preferred options, considering environmental effectiveness, political and legal feasibility.

The most effective policy option is to implement a mandatory and harmonised speed limit for ships as a condition of entry to Member States' ports. Exemptions for certain trades, voyages or ships should however be considered.

Ideally, Blue Speeds would be implemented as a limitation of the maximum speed of ships, sailing to and from EEA ports (100% intra- and 100% extra-EEA incoming and outgoing voyages), including, by default, all ship types and sizes and all types of voyages and, ideally, Blues Speeds would be implemented at the highest possible political level. Speed limitations should be differentiated per ship type and size. A maximum speed limit set at 75% of the design speed is considered feasible. As this is an ambitious target, more lenient individual targets in case of technical limits or potential undesired effects should be considered. And the baseline design speeds on which the speed limitations will be based should be carefully determined to balance the effectiveness while not punishing early adopters. If an engine power output limitation can be implemented, this is the preferred option to limit the ships speed in terms of speed through the water. Otherwise, a limit in terms of speed over ground has to be set and the ships' speed must be actively monitored by means of, for example, AIS. Since the smallest cargo carrying ships (<300 GT on international voyages and <500 GT on non-international voyages) are currently not required to be equipped with an AIS transponder, the smaller cargo carrying ships could, at least in the short-term, not be included.

We have analysed the impact of Blue Speeds, using 2018 data, published in the context of the EU MRV (Monitoring, Reporting and Verification) Regulation. The analysis shows that implementing Blue Speeds would require several ship types and size categories (29 out of the 49 categories differentiated) to reduce their average speed. Overall, the average speed would have to be reduced by around 5% at the fleet level, with the highest relative speed reduction potential (more than 10% reduction) for medium-sized chemical tankers, large container ships, small general cargo ships, refrigerated cargo ships and Ro-Pax ships of all sizes.

When ships have to reduce their speed, transit time would increase, meaning that additional shipping capacity is required to provide an unchanged amount of transport work. Assuming that this extra capacity is provided by ships of the same ship type and size category as the ships that have to reduce their speed and assuming that these are ships that have to be added as newbuild ships to the fleet, almost 200 ships would have to be added to the EU MRV fleet due to Blue Speeds. Despite this, Blue Speeds would still lead to a net reduction in URN produced by the EU MRV fleet - a decrease of around 25% of the sound energy released. The actual URN reduction that can be achieved by Blue Speeds however depends on local factors, traffic density and the actual ships active in the area under consideration.

Blue Speeds were also found to lead to a net reduction in energy consumed, CO_2 emissions and air pollutants emitted by the EU MRV fleet, even when accounting for the additional capacity required (provided by newbuild ships) and the associated CO_2 emissions of the building of these ships.

The effects of Blue Speeds on the 2018 EU MRV fleet were also analysed in a social cost-benefit analysis, considering changes in fuel expenditures, in carbon costs (if the fleet was included in the EU Emissions Trading System (ETS)), in financing costs (due to longer transits), costs accruing for the additionally required ship capacity and for engine modification costs. The impacts on climate, health and environment due to the change of CO_2 and air pollution of the sector (SO_x, NO_x) as well as the reduction of the hazard of ship strikes to whales were considered too.

The social cost-benefit analysis showed that, depending on the fuel price and the EU ETS allowance price, the sectoral benefits of Blue Speeds (fuel and EU ETS expenditure savings) can outweigh the sectoral costs of Blue Speeds. Also considering the positive environmental effects of Blue Speeds, the overall benefits would outweigh their costs for a wide range of fuel prices.

If there is overcapacity available in the shipping market, the presented costs associated with Blue Speeds can be further reduced, because the capacity of existing ships could be used to supply extra transport work instead of new ships. A complementary measure, to facilitate the optimisation of port logistics with the aim to accommodate Blue Speeds and reduce waiting time instead could significantly reduce the need for more vessels, to adjust logistic chains and thus also the costs associated with Blue Speeds.

Should the Energy Efficiency Existing Ship Index (EEXI), the FuelEU Maritime Regulation and/or the EU ETS incentivise ships to reduce their speed independent of Blue Speeds, then some of the benefits of Blue Speeds would already occur. Compared to the FuelEU Maritime Regulation and EU ETS, however, Blue Speeds would ensure that ships permanently reduce their speed.

Blue Speeds could be implemented as a separate Regulation/Directive and could be brought forward as an alternative if maritime shipping was not successfully included in the EU ETS. Alternatively, Blue Speeds could be implemented through the Marine Strategy Framework Directive (MSFD), which has to be reviewed by 2023: a coordinated implementation by a subset of Member States/of European Regional Sea Conventions with competing ports is conceivable as part of their updated programme of measures as part of the MSFD. It would however have to be clarified whether mandatory Blue Speeds are within the competence of a subset of Member States/of countries affiliated to European Regional Sea Conventions. As an alternative, recommendations for community action (see MSFD, Article 15) for the implementation of Blue Speeds at the EU level could be developed and submitted to the European Commission.

1 Introduction

1.1 Underwater Radiated Noise (URN)

There are many different sources of sound in the ocean, both natural and human (anthropogenic), all of which contribute to the underwater soundscape. Explosions, airgun arrays and navy sonar are major sources of impulsive noise, while ships produce continuous sounds, covering a wide range of frequencies from low to high (EMB, 2021). The largest contributor of low frequency anthropogenic noise to the marine environment is commercial shipping (MEPC 73/INF.23). Sound measurements during the COVID-19 pandemic confirmed this, showing a significant decrease in ocean noise levels concurrent with lower shipping activity (Dunn, et al., 2021).

URN has a negative impact on the marine environment and, since sound propagates four times faster and travels much longer distances in water than in air, shipping noise can affect animals that are many kilometres away from the noise source (DNV, 2021). The sound that ships emit depends on both the design and the operation of the vessel, with larger ships generally producing more intense sound levels at lower frequencies (EMB, 2021). The primary source of underwater noise from ships is the propeller, but equipment used for the propulsion of the ship and the flow of water over the hull are also sources of sound (Hildebrand, 2004). Propeller motion creates noise by cavitation: the low-pressure area around the blades produces tiny bubbles that burst and result in noise.

Technical measures can contribute to a reduction of URN by ships, but can be costly, especially for existing ships. A reduction in the speed of ships is an operational measure to reduce shipping noise, which can potentially lead to a significant reduction in the noise produced by ships.

The study investigates a limitation of the speed of ships to implement 'Blue Speeds' - speed levels that protect the marine environment from negative impacts of URN and that are associated with co-benefits for both marine life and humans by reducing the hazard of ship strikes to whales, GHG emissions and air pollution.

1.2 Blue Speeds to reduce URN from maritime shipping

The report analyses Blue Speeds, a measure that limits the speed of ships engaged in EU-related maritime transport with the aim of protecting the marine environment from the negative impacts of URN and that is associated with co-benefits for marine life and humans by reducing the hazard of ship strikes to whales, GHG emissions and air pollution.

More specifically, a social cost-benefit analysis is carried out on a maximum speed limit for ships, with a speed limit set at 75% of the ships' design speed. The social costs and benefits are thereby quantified as far as possible, in line with an anthropogenic approach. Co-benefits in terms of fewer potential collisions with whales (known as 'ship strikes') and lower GHG and air pollution emissions from ships are also considered in the analysis.

Prior to the social cost-benefit-analysis (Chapter 5), we give an overview of the effects of URN on the marine environment (Chapter 2) and discuss alternative technical and operational options to mitigate ships' URN (Chapter 3). Chapter 4 analyses the regulatory options to reduce ship speeds, identifying preferred design and implementation options for Blue Speeds. Chapter 6 sets out the final conclusion.

2 The effects of URN on the marine environment

Sound plays a very important role for several underwater species, allowing them to gather information and interact with the environment. Essential aspects of marine life could therefore be at stake due to underwater noise pollution. In the following, we will present an overview of the impact of URN on marine mammals, fish and invertebrates, mainly based on EMSA (2021) and Wielgart (2018).

2.1 Impact of URN on marine mammals

Marine mammals include different groups of species. Since this study focuses mainly on Europe and the impact of underwater noise from shipping, this section will include the groups of species that occur in European waters and use sound underwater. These groups of species include:
- cetaceans: dolphins and whales;
- pinnipeds: seals, sea lions and walruses.

While cetacean species are exclusively underwater animals, pinnipeds are considered amphipods, which means that they can live both on land and underwater. Most published studies about underwater noise effects on marine life focus on marine mammals, therefore this will also be our main focus.

Cetaceans

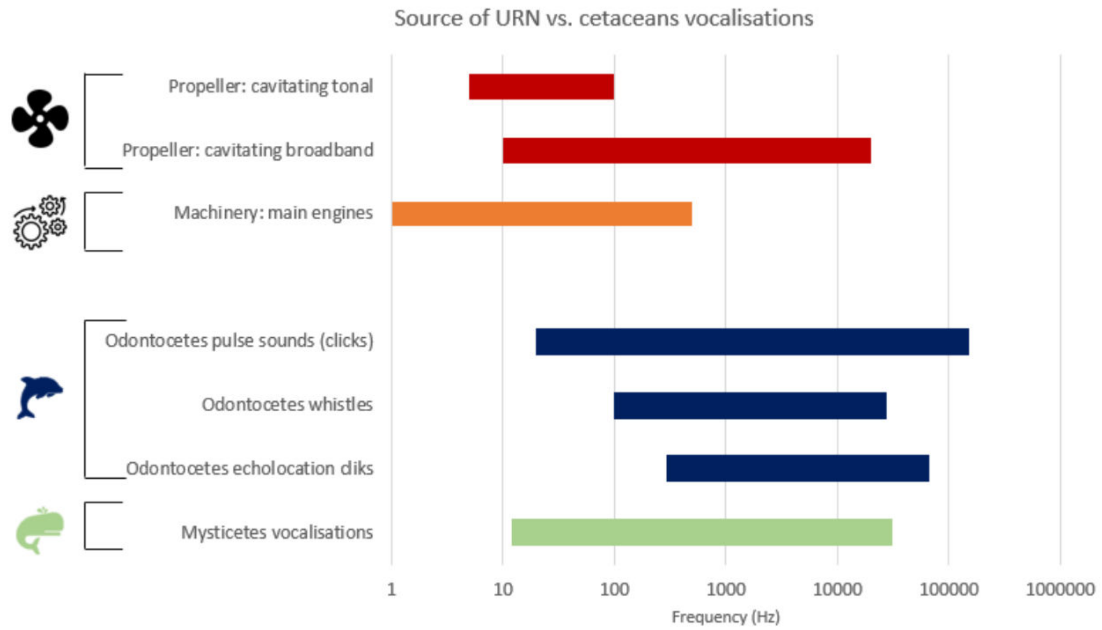
Cetaceans use sound for several activities, including social interaction, finding prey, avoiding obstacles and navigation. For these activities they are not only able to detect sound in their environment, they are also able to produce different types of acoustic signals, using air sacs located near their blowhole.

Depending on the species, different sounds can be produced for social interaction. Whistles are commonly used by marine mammals, in particular by toothed whales. There is evidence that whistles are used when dolphins meet or join a group at sea (Quick & Janik, 2012), known as signature whistles. Whistles can also be used to maintain close contact, such as between a mother and her calf (Janik & Sayigh, 2013), or to maintain cohesion among groups (Riesch, et al., 2006). Signature whistles of bottlenose dolphins are particularly well studied (Janik & Sayigh, 2013), but there is evidence that they are also used by other species, such as spotted dolphins (Caldwell, et al., 1973) and common dolphins (Fearey, et al., 2019). Clicks are also used as social vocalisation, such as the use of codas (stereotyped click sequences) by sperm whales to maintain clans (Rendell & Whitehead, 2003) or the use of specific patterns of clicks by harbour porpoises (Clausen, et al., 2011).

Clicks can be grouped in two main categories, echolocation clicks and burst pulsed sounds. Echolocation clicks are used by dolphins (Au, 2018) to acquire a sense of their surroundings, such as to detect obstacles during navigation (Popper & Pilleri, 1985). Burst pulsed sounds can be used in different contexts, including social interaction. For example, sperm whales use squeals for feeding (Weir, et al., 2007), Risso's dolphins use buzzes to capture prey (Arranz, et al., 2016) and bottlenose dolphins use burst pulsed sounds for agonistic or aggressive interaction (Blomqvist & Amundin, 2004).

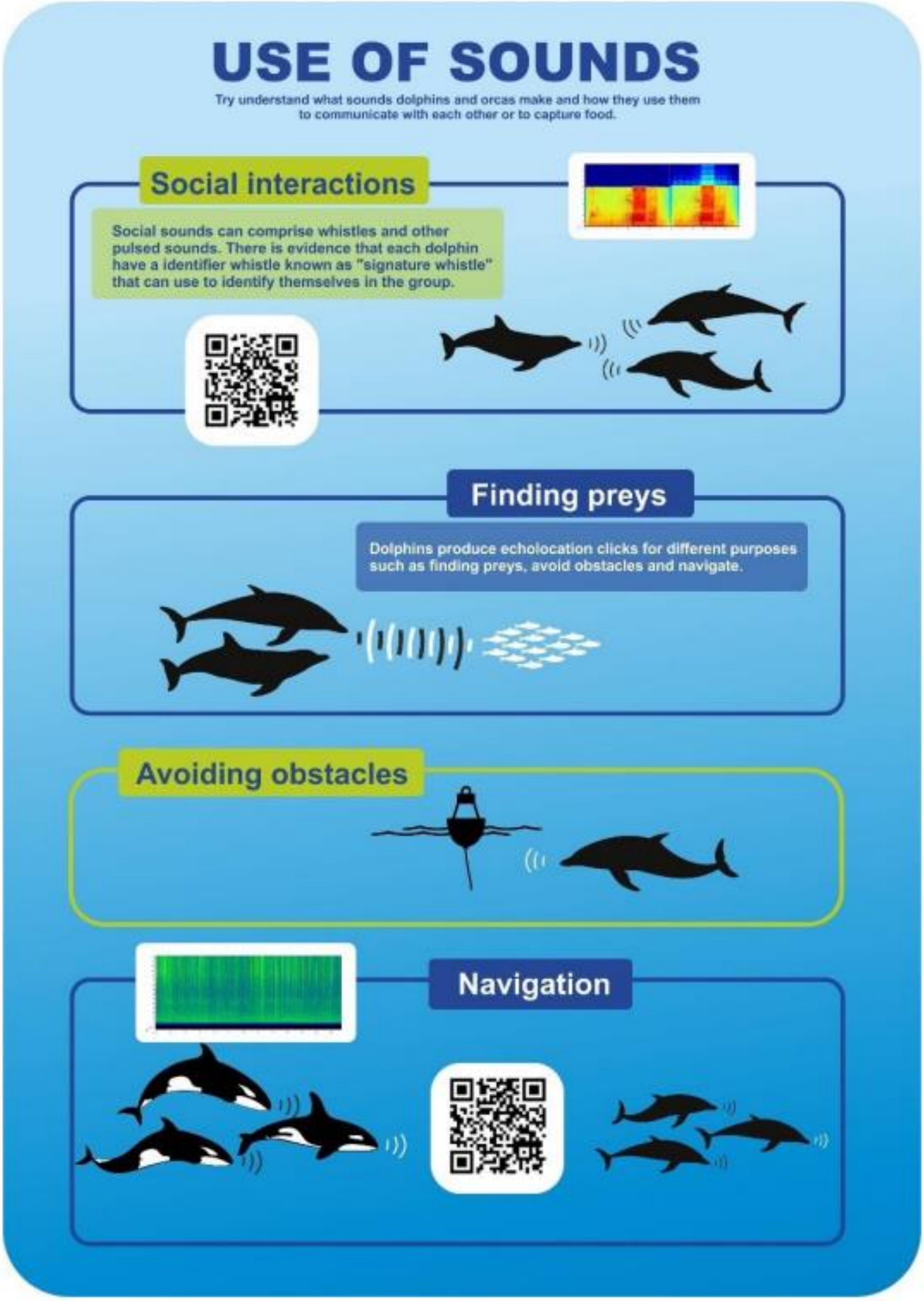
Figure 1 presents the overlap of frequency ranges of different sources of underwater noise from shipping and different types of vocalisation emitted by cetacean species. Figure 2 presents the different activities for which cetacean species use sound.

Figure 1 – Frequency range of shipping noise and different types of vocalisations produced by cetaceans. The frequency ranges are based on the minimum and maximum values of frequencies found in literature for the different types of vocalisations. The red colour indicates a high contribution of URN, orange indicates a medium contribution.



Source: EMSA (2021).

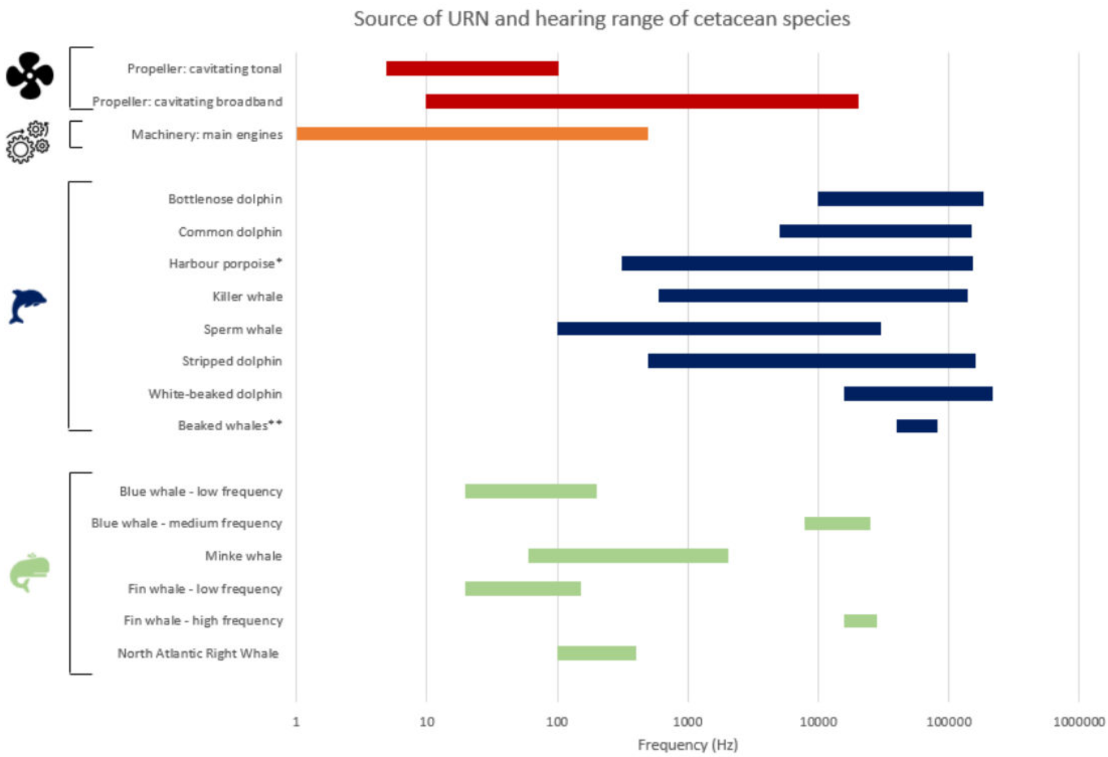
Figure 2 – Use of sound by cetacean species. The sounds are indicative of the situation where they can be found and are not directly related with the species represented in the picture.



Source: EMSA (2021).

Figure 3 presents a review of the hearing range of the most abundant and common species that are identified as being impacted by underwater noise. Shipping noise overlaps in part with the hearing range of most of the species.

Figure 3 - Frequency range of shipping noise and hearing range of cetacean species. A distinction is made between odontocetes (dolphin species) and mysticetes (baleen whales) due to the difference in their hearing sensitivity.



Source: EMSA (2021).

Several studies show that shipping noise can affect cetaceans leading to behavioural and acoustic responses, auditory masking and stress (Erbe, et al., 2019). Common behavioural changes can include changes in diving, swimming direction and group structure. Common acoustic responses include changes in the frequency of calling (Heiler, et al., 2016), the duration of calling (Blomqvist & Amundin, 2004) and calling amplitude (Holt, et al., 2009).

— **Changes in vocal behaviour:** The rate of vocalisations can increase or decrease in the presence of vessels. For example, bottlenose dolphins can reduce the rate of whistles and echolocation clicks in the presence of vessels (Luís, et al., 2014), but they tend to increase the rate after the vessel passes (Buckstaff, 2004), probably as an attempt to keep the group together. It was also observed that in the presence of calves, the animals increase the number of whistles probably in order to ensure that mother/calf pairs remain with the group (Guerra, et al., 2014). Buckstaff (2004) was able to identify changes in whistle rate and the number of whistles in relation to estimated received levels ranging from 115 to 138 dB re 1 µPa. Castellote, et al., (2012) found that fin whales 20-Hz note duration shortened, bandwidth decreased, centre frequency decreased and peak frequency decreased in the presence of high background noise levels resulting from shipping.

- **Changes in diving and swimming patterns:** Au & Green (2000) show evidence that humpback whales appeared to swim faster in the presence of boats. However, they indicate that it is very difficult to assess if the reaction was caused by the noise from the vessels or if it is related to other factors such as the size or shape of the vessel. The reactions were observed in the presence of an inflatable boat where the highest spectral peak was 121 dB at 3.1 kHz.
- **Reduction in the communication range:** A study carried out by Castellote, et al., (2018) provides evidence of the potential for commercial shipping to mask beluga whale communication and hearing, with commercial shipping peaked in the band centred at 630 Hz and a SPL was above 115 dB re 1 μPa^2/Hz.
- **Foraging behaviour:** A study from Aguilar de Soto, et al., (2006) provides evidence that Cuvier's beaked whales present a shorter vocal phase during a foraging dive in the presence of a commercial ship. This was observed at a received level of 136 dB rms re 1μPa, in the frequency range between 356 Hz and 44.8 KHz. However, a study carried out by André, et al., (2017) showed no evidence that shipping noise influences the behaviour of sperm shales. Blair, et al., (2016) provided evidence that humpback whales change their foraging behaviour, presenting slower descent rates and fewer side-roll feeding events per dive with increasing ship noise related to a large ship. Noise levels or frequency ranges were not described in this study.
- **Physiological:** Few studies analyse physiological responses of marine mammals to underwater noise from shipping. Rolland, et al., (2012) highlighted the possibility of chronic stress in the North Atlantic right whales due to their exposure to low-frequency ship noise. They detected a decrease in baseline levels of stress-related faecal hormone metabolites associated with the reduction of underwater noise levels due to a reduction of ship traffic.
- **No impact on the auditory system:** A study conducted by Au & Green (2000) provided evidence that level of noise produced by inflatables with outboard engines, larger coastal boats with twin inboard diesel engines and small water plane area twin hull (SWATH) ships are unlikely to affect the auditory system of humpback whales.

Not all studies refer to the operational conditions of the vessels, but those that do usually refer to the speed. Few of the studies mention the noise source levels, received levels or changes in background noise levels due to the presence of vessels. This presents a constraint on the identification of frequencies and sound pressure levels of observed impacts. Another limitation is that studies that do mention noise source levels, received levels or changes in background noise levels, do not use a common metric. Some mention the frequency range of the record and the broadband sound pressure levels, while others opt to refer only to the frequency of the observed response.

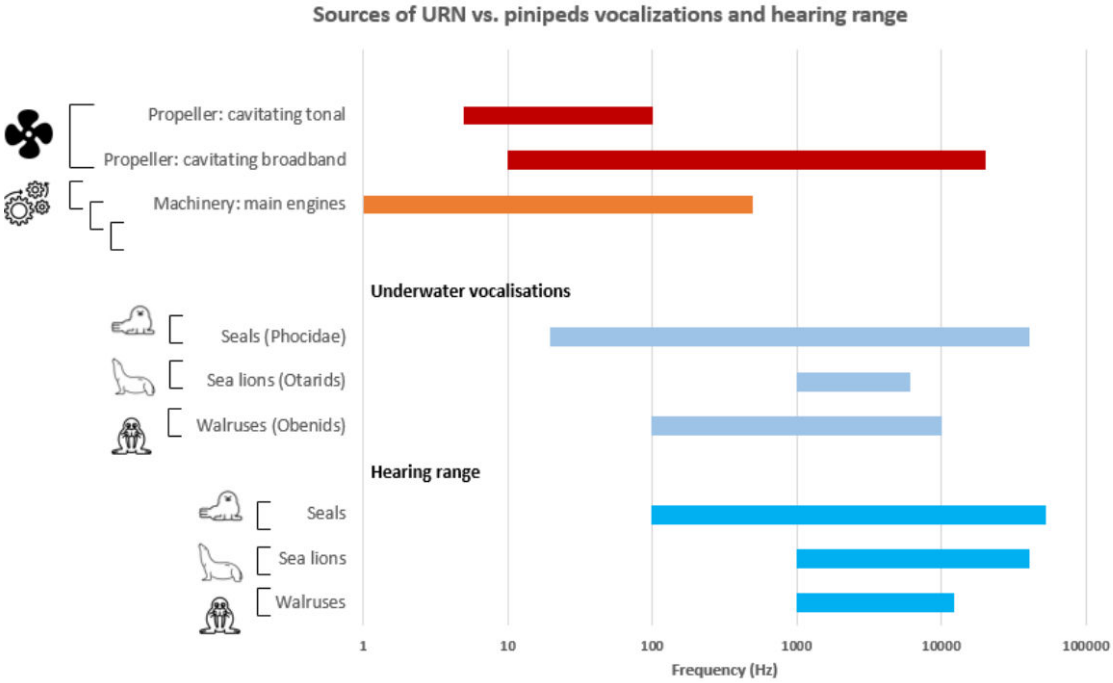
Pinnipeds

Pinnipeds are amphibious and therefore use airborne and underwater sounds. They can produce sounds using their larynx, with the same mechanism as land mammals.
Their hearing mechanism is somewhat adapted compared to land mammals, such that they can also hear underwater sound properly.

Underwater sounds produced by pinnipeds correspond mainly to pulsed sounds, some of them similar to the ones produced by cetaceans. The frequency range depends on the type of vocalisation and the group of species. Vocalisation produced by seals range from 20 Hz to 40 kHz, for sea lions from 1 to 6 kHz and walruses from 10 Hz to 10 kHz.

Considering the underwater hearing frequency ranges, existing studies indicate that pinnipeds have better sensitivity for sound above 1 kHz. Figure 4 displays the frequency ranges of sources of underwater noise from shipping and pinnipeds vocalisation and hearing range. It is clear that sources of shipping noise overlap with the hearing range of pinnipeds.

Figure 4 - Frequency range of underwater noise sources from shipping and of hearing and vocalisation of pinnipeds. The red colour of propeller sounds indicates a high contribution to underwater noise, the orange colour of machinery sounds indicates a medium contribution to underwater noise.



Source: EMSA (2021).

Only a few studies address the impact of underwater noise on pinnipeds that can be found in European waters (Erbe, et al., 2019). Most of the studies do not provide direct evidence that the response observed is directly related to underwater noise from shipping. However, these studies mention the observation of responses in the presence of high background noise levels as a result of shipping. Potential effects of noise from shipping are:

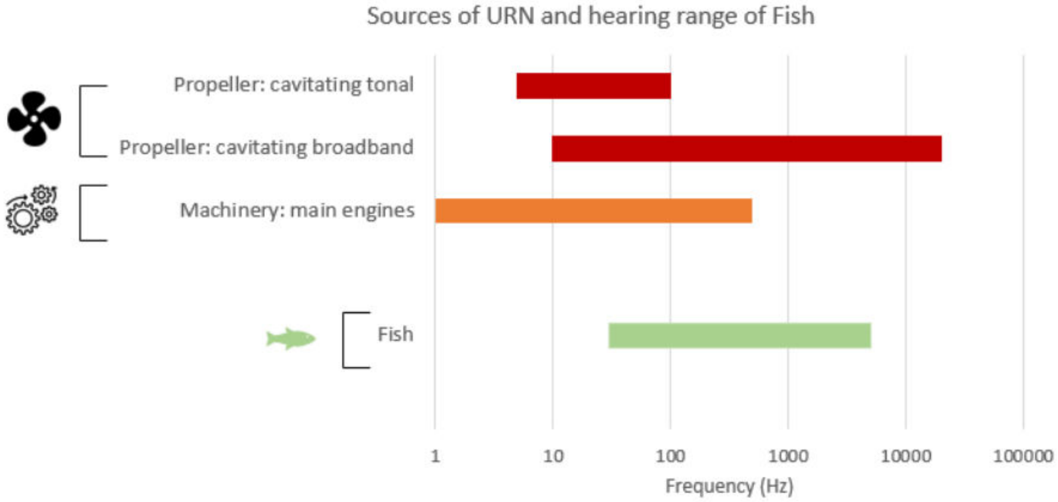
- **Behavioural changes:** including look, dive and swim behaviour (Harris, et al., 2001) and aggressive behaviour (Osterrieder, et al., 2017). Mikkelsen, et al., (2019) demonstrated that the interruption of functional behaviours, for example resting, in some cases coincides with high-level vessel noise.
- **Masking:** Gabriele, et al., (2018) found evidence that behavioural changes may lead to a reduction of communication space. Potential masking, which can lead to reduced abilities to detect, recognize or understand sounds of interest, was observed by Bagočius (2015). According to this study the detection distance of calls between animals of the same species can be significantly reduced in the presence of local shipping.
- **Vocal changes:**Terhune, et al., (1979) demonstrated that a marked decrease in seal vocalisations occurred following the arrival of a vessel. The relatively loud motor noises of the vessel completely masked the seal calls within a radius of 2 km or more. The author suggested that this might result from a behavioural change of the seals or a displacement of the animals.

No studies have been found showing the direct effect of URN from shipping on the survival or ability to reproduce of marine mammals. However, in view of the clear overlap in shipping URN frequencies and vocalisation and hearing frequencies of marine mammals, it is likely that effects can be induced. The masking of communication calls, some of which may help coordinate foraging or prey sharing, could have serious consequences. Especially in an environment where marine mammals are already food-stressed, for example due to reduced populations of their prey, masking of communication could be critical and potentially lead to diminished chances of survival.

2.2 Impact of URN on fish

Sound is a key sensory cue for fish to perceive their environment. They use sound for communication, navigation, orientation, mating, foraging and predator avoidance (Popper, 2003). All fish studied to date can detect sound typically in the range of 30 to 5,000 Hz (Slabbekoorn, et al., 2010), which overlaps with relevant sources of shipping noise, see Figure 5.

Figure 5 - Sources of underwater noise from shipping and the hearing range of fish species. The red colour for propeller noise indicates a high contribution to underwater noise, the orange colour indicates a medium contribution.



Source: EMSA (2021).

A large number of published papers and reports have pointed out the short-term, transient effects and the serious long-term, chronic effects on fish caused by noise. Such effects were observed from monitoring surveys and laboratory or modelling experiments, see for example Weilgart (2018).

Short-term effects are generally related to noise acting as a distracting stimulus, a stressor or by masking important acoustic signals, such as altering species' home ranges and swimming behaviours and influencing the outcome of predator-prey interactions (Velasquez Jimenez, et al., 2020). The many short-term effects from noise may have implications for the survival or ability to reproduce of a species, potentially leading to serious longer-term effects in the overall population dynamics, structure and functioning ((Weilgart, 2018) and (Slabbekoorn, et al., 2010))

The effects of anthropogenic noise on fish are often grouped into anatomical, physiological and behavioural responses. According to de Jong, et al., (2020) the underlying mechanisms that influence those responses can be defined as (1) stress, (2) masking and (3) hearing-loss:

- **Stress inducing behavioural responses:** Stress can affect signalling and avoidance behaviour, growth, sexual maturation, reproduction, immunity and survival (de Jong, et al., 2020). The primary response to stress is associated with neurological and hormonal responses, priming the animal for a fight, flight or freeze response. There are several studies, such as La Manna, et al., (2016), that show that underwater radiative noise from shipping caused longer fish flight reactions, increased the amount of hiding and caused resident fish to be more submissive and to win less physical encounters. If stress is prolonged (for example if fish remain close to a busy shipping route), it can lead to chronic stress inducing physiological changes such as a decrease in body condition, reduction in growth and a hampered immune system. After two to three weeks of continuous stress, reproductive physiology may also be impaired (de Jong, et al., 2020).
- **Masking:** URN from shipping can overlap in frequency with, and therefore mask, biologically significant signals. Masking of sounds made by prey organisms may result in reduced feeding with effects on growth. Masking of sounds from predators may result in reduced survival. Masking of spawning signals may reduce spawning success and affect recruitment (the process by which very young fish survive). Masking of sounds used for orientation and navigation may affect the ability of fish to find preferred habitats including spawning areas, affecting recruitment, growth, survival and reproduction (de Jong, et al., 2020).
- **Hearing loss:** Either temporary or permanent hearing loss and impaired temporal resolution can be caused by high-intensity acute noise, as well as prolonged exposure to lower intensity noise. Hearing-loss will have similar effects as masking, but will be prolonged. Impairment of hearing may affect the ability of fish to capture prey and avoid predators, and causes deterioration in communication, affecting growth, survival and reproduction success. The most serious impact is on survival and reproduction, because these have population consequences. Noise may have many detrimental effects on a species fitness, for example on mate localisation and choice and on courtship, reduced spawning, heightened parental aggression and defensive behaviour, often leading to lower offspring survival (de Jong, et al., 2020). For many fish species the spawning period may be particularly sensitive to impact from noise and negatively affect a much larger fraction of the population compared to other periods of the year (Pörtner & Farrell, 2008).

Fish seem to be seriously affected by underwater radiative noise. Studies show noise effects have implications for the survival or ability to reproduce of fish, which could lead to long-term effects on the population size. This has implication for the fishing sector. Some commercial catches have been found to drop by up to 80% due to noise, with larger fish leaving the area. Bycatch rates also could increase, while abundance generally decreased with noise (Weilgart, 2018). Once the population biology and ecology are impacted, it is clear fisheries and even food security for humans are also impacted.

2.3 Impacts of URN on invertebrates

The group of invertebrates includes a variety of species such as lobsters, crabs, octopus, corals, anemones, sea stars, sea urchins and shrimps. The mechanisms on how they use sound have not been studied in detail, with the exception of spiny lobsters, semi-terrestrial crabs and snapping shrimps. It is assumed that invertebrates do not respond to acoustic stimulus but respond instead to particle motion (Popper & Hawkins, 2018), which relates to the vibrations of the medium where sound waves propagate. These animals use specialised structures such as external sensory hairs, internal statocysts and other sensory organs to detect pressure changes. Marine invertebrates are able to produce sound by rubbing two body parts together, known a stridulation or rapid muscle contractions, usually in relation to defence and courtship behaviour.

There is evidence that invertebrates can present behavioural reactions, morphological and physiological changes and damage of sensitive organs, as a result of underwater noise.

- **Changes in locomotive patterns:** Common prawn and Mediterranean spiny lobster showed changes in locomotive patterns when subject to noise from different types of boats (recreational boats, fishing, ferry and hydrofoil) in the frequency range from 300 to 3,000 Hz. Locomotive patterns appear to be related with social aspects (Filiciotto, et al., 2014).
- **Increases in settlement behaviour:** It is suggested by different studies that vessel noise increases settlement of mussel larvae (Wilkens, et al., 2012). The impact appears to correlate with the intensity of the sound. Other studies indicate that vessel noise may be attracting, as well as promoting, the settlement and growth of the larvae of key fouling organisms of vessel hulls (Stanley, et al., 2014).
- **Increases of stress:** An increase in stress hormones was found in the common prawn when subjected to playback of different boats (Filiciotto, et al., 2014). Wale, et al., (2013) showed that shore crab increases oxygen consumption during a first exposure to ship noise ranging from 148 to 155 dB. This reaction is size dependent with heavier crabs showing a stronger response than lighter crabs. The same study indicates the potential for habituation, since repeated exposure to ship-noise playback produced no change in physiological response.
- **Limiting bioaccumulation and slowing down growth rates:** Oysters exposed to URN from shipping accumulated less Cadmium in their gills, probably due a reduction of valve activity, slowing their growth rate (Mohcine, et al., 2018).
- **Morphological effects:** Vessel noise affects embryo development and mortality of larvae. According to Nedelec, et al., (2014) vessel noise reduced successful development of embryos by 21% of sea hare and contributed to a 22% increase in mortality of recently hatched larvae.

Ecological services performed by invertebrates, such as water filtration, mixing sediment layers and bio irrigation, which are key to nutrient cycling on the seabed, were negatively affected by noise (Weilgart, 2018).

3 Options to mitigate ships' URN

3.1 Alternative technical and operational options to mitigate URN

Underwater noise from commercial shipping can be mitigated by means of technical and operational mitigation measures. This section provides a global overview of the various options, mainly based on ABS (2021).

3.1.1 Mitigation of underwater noise by means of technical measures

There are different technical options to mitigate URN from ships. The following four main types of technical URN mitigation measures can be differentiated and will be discussed in more detail in the following:
1. Propeller related technical measures.
2. Hull related technical measures.
3. Machinery related technical measures.
4. Alternative power sources.

The vast majority of commercial vessels currently in use have been designed without considering URN reduction. This is because parts of shipbuilding are highly standardised, but also because the measures are associated with additional costs and/or other disadvantages from the perspective of the ship owner. Cruise, research and military vessels are an exemption in this context, and low sound and vibration levels play an important role in their operation.

Propeller related technical measures

Most ship propulsion systems provide thrust through one or more screw propellers. URN generated by propellers is mainly caused by certain types of cavitation (tip vortex cavitation, blade sheet cavitation, hub vortex cavitation, etc.). Propeller-induced cavitation is generally considered to be the main source of underwater noise made by commercial vessels, particularly at higher speeds.

To reduce propeller-related URN, cavitation can be reduced by means of:
- propeller design;
- wake optimisation;
- other propulsion enhancement measures.

Propeller design

Some propellers are designed and selected to reduce cavitation. Good design to reduce cavitation includes optimising the propeller load, ensuring water flow that is as uniform as possible into the propellers, and the careful selection of propeller characteristics (diameter, blade number, pitch, skew and sections) (Nolet, 2017).

Wake optimisation

A well-regulated hull **wake** can enhance propulsive efficiency, reduce propeller cavitation and reduce propeller-radiated underwater noise. There are a variety of wake improvement devices, such as ducts, propeller boss cap fins or stern flaps. To be effective, the selected device has to be suitable for the hull shape, propeller design, and operating profile of the vessel.

Other propulsion enhancement: Air injection

Propeller cavitation can be reduced by injecting air directly into the cavitating region or noise radiation can be attenuated by generating an isolating air bubble layer around the propeller and its downstream flow. From measurements performed in the SONIC project, this approach was found to result in URN reductions of 10-15 dB in the frequency range of 40-400Hz (AQUO & SONIC consortia, 2015).

Hull related technical mitigation measures

There are different hull related technical mitigation measures which will be explained in the following:
- hull form optimisation;
- hull structure optimisation;
- double hull design;
- air lubrication systems;
- application of decoupling coating;
- air bubble curtain;
- masker system.

Given that uneven or non-homogeneous wake fields are known to increase cavitation (with a propeller operating in the wake field generated by the ship hull), the ship’s **hull form** should be designed in such a way that the wake field is as homogeneous as possible (Nolet, 2017). Improper design of appendages and hull openings (for example for cooling water intake) can lead to local cavitation or flow-induces noise. Asymmetric design of the aft body can improve the wake flow into the propeller of a single screw merchant ship (ABS, 2021).

Optimisation of the hull structure (mass, stiffness and damping) can potentially reduce the underwater radiation of structure-borne and air-borne machinery noise. This is only relevant when machinery noise exceeds propeller noise.

Double hull designs can decouple the foundation structure from the outer hull plate, which can reduce the structure-borne sound transmission from the machinery foundations to the outer hull plate.

Air lubrication systems can be installed to reduce the hull’s frictional resistance, which is likely to also reduce machinery noise radiation by decoupling the vibrating hull from the surrounding water.

Decoupling can also be achieved by the application of a flexible hull coating, such as decoupling techniques that are used on naval vessels (submarines as well as surface ships) with stringent acoustic signature requirements. It is only effective for vessels where machinery noise dominates propeller noise.

Another approach is to generate an **air bubble curtain** around the aft part of the ship hull, also referred to as a '**Masker system**'. Such systems were designed to reduce machinery noise from naval vessels, with similar systems being applied to merchant ships. The systems result in an insertion loss due to the impedance difference between air and water, but require tuning in order to reduce noise across the desired frequency range. It should be noted that such a system is distinct from an air lubrication system aimed at reducing ship hull frictional resistance.

Machinery related technical mitigation measures

Machinery-induced underwater noise is mainly generated by structure-borne sound. The machinery vibration can transmit to the foundations and then propagate to the hull structures; machinery airborne noise can also contribute to structure-borne noise.

The technology required to reduce machinery noise is well-established. The main noise-control measures are:

- Low-noise machinery can be installed. A combination of, on the one hand, an electric engine and, on the other hand, a diesel generator or fuel cell to produce electricity, are examples of machinery with relatively low noise levels. Also gas and steam turbines are in general quieter and produce lower vibration levels.
- The location of the equipment in the hull and how it is mounted also plays an important role. Diesel-electric propulsion systems, for example, offer the possibility to mount the diesel engines higher up inside the ship structure in order to better isolate them from the hull plating. Installing machines on resilient mountings or on resiliently mounted deck structures also lead to a reduction of the transmission of structure-borne noise. The vast majority of commercial vessels have 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.
- To avoid vibration energy of the machinery equipment being directly transmitted to the foundation, two-stage insulation can be applied, providing an extra barrier to the transmission of vibration energy.
- Using damping and absorbing layers on surfaces to reduce the transmission of structure-borne noise and airborne noise.
- By means of acoustic enclosure, engine airborne noise, which contributes to structure-borne noise as well as URN, can be absorbed.
- Active vibration cancellation can be applied to produce a counter phase excitation to offset the machinery vibration excitation.
- Resilient suspension of pipes, cables, etc. and the installation of flexible shaft couplings and bellows contribute to a reduction of the transmission of structure-borne noise.

Alternative power sources

Alternative power sources can contribute to a reduction of the required engine power and the amount of thrust to be generated by the ship's propeller. Systems like wind propulsion systems or onshore power systems can therefore contribute to a reduction of URN of ships.

3.1.2 Noise mitigation in ship operation

Speed reduction

Ships equipped with fixed pitch propellers can reduce or eliminate propeller cavitation by reducing their speed.[1]

The Vessel Noise Correlation Study, as part of the ECHO Program, investigated correlations between vessel URN levels, design characteristics and operating conditions for six major commercial vessel categories. One of the outcomes of this study was that '[v]essel speed over water and actual vessel draft remained the most influential predictors of vessel underwater radiated noise levels in all six vessel categories' (Vancouver Fraser Port Authority, 2021).

Reducing the speed of a ship can be considered an operational measure, but implementation of the measure can also require technological changes onboard ships.

Newbuild ships could be designed and optimised to operate at lower than conventional speeds. Existing ships' engine power could be limited/engines could be de-rated. Engine power limitation (EPL) is one of the options to comply with the Energy Efficiency Existing Ship Index which will come into effect at the beginning of 2023 (for more details see Section 4.3). The engine power of an existing ship can be limited by limiting the fuel rack using either a mechanical stop or setting the control system in combination with an approved override functionality (DNV, ongoing). Examples for flexible and reversible de-ratings measures are:
- installing shims between the crosshead and piston rod to reduce stroke length;
- cutting out one or several turbochargers, either with permanent or flexible flanges;
- cutting out/deactivating cylinders;
- various tuning methods/settings of the engine, incl. slow steaming kits (also for retrofit).

(DNV GL, ongoing).

The engine power can also be permanently limited by, for example, permanently cutting-out a turbo charger (DNV, ongoing).

Regular maintenance

Regular hull and propeller maintenance for improved efficiency will indirectly reduce underwater radiated noise, since by decreasing the frictional resistance of the hull and/or propeller the same vessel speed can be maintained with less propulsion power (AQUO & SONIC consortia, 2015). Anti-fouling and low-friction coatings can also be applied to the ship hull to reduce resistance, or avoid accumulation of bio-fouling.

[1] Propeller blades can have fixed blade angles (fixed pitch) or adjustable blade angles (controllable pitch). Pitch control enables the adjustment of the thrust (and therefore ship speed) independent of the rotations per minute. 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 optimised with respect to cavitation performance and noise.

Real-time monitoring

It is possible to provide additional information to the ship's master or make better use of the available information in order to reduce underwater radiated noise by means of operational measures. For example, optimising vessel trim can reduce the required power and therefore also propeller cavitation noise. If controllable pitch propellers are operated following combinator curves, both higher fuel efficiency and lower noise may be achieved. Another option is to install sensors to monitor cavitation, such that an appropriate speed can be selected depending on where the vessel is sailing.

3.2 Assessment of options

There are technical design options that can significantly reduce URN of ships.[2] To be effective, these options should be considered at an early design stage, which requires close collaboration between shipyards, designers and owners. Ideally, to be applied on a large scale, standardised solutions, suitable for serial production should be developed.

There are technical retrofit measures that can clearly reduce ships' URN. The overall reduction potential of retrofit measures is, however, most probably lower compared to integral solutions considered at the design stage. And "[f]ixing underwater noise issues after construction could be difficult and expensive" (ABS, 2021).

Some technical measures (design/retrofit) do not have the co-benefit of energy efficiency improvements (e.g. damping or isolation) or even require extra energy (e.g. air bubble curtain), which is why there is currently no incentive to apply these measures.
This probably also hampers financing of such measures.

Speed reduction can be a very effective measure to reduce a ship's URN, especially for existing ships. Compared to other measures, speed reduction can contribute to a reduction of low, medium and high frequency noise and can potentially reduce URN of all ship types/sizes, at least if they are not equipped with a controllable pitch propeller (Bureau Veritas, et al., 2015). Speed reduction is associated with the co-benefits of improved energy efficiency, reduced GHG emissions and air pollutants, and potentially less ship strikes.

[2] A technical standard, setting URN requirements for newbuild ships could therefore be a useful option too. A speed limit for existing ships could then serve as an interim solution until, due to fleet renewal, the entire fleet fulfils the URN standards. In contrast to a speed limit, a technical standard can, however, not offer the co-benefits of reduced GHG and air pollution emissions as well as a decreased hazard of ship strikes.

4 Analysis of regulatory options

4.1 Introduction

Currently, maximum noise level limits apply to machinery spaces, control rooms, workshops, accommodation and other spaces on board ships to prevent an adverse impact on human health (IMO, ongoing b). Directive 2003/10/EC also lays down minimum requirements for the protection of workers from risks to their health and safety arising from, or likely to arise from, exposure to noise. There are, however, no mandatory limits for noise levels to prevent adverse effects of URN of ships on the marine environment.

The focus of this report is the reduction of URN of ships by means of the reduction of the speed of ships. Before discussing the design and implementation options and determining the preferred options for a measure to reduce the speed of ships (Section 4.5), we briefly discuss existing guidelines/frameworks/initiatives that address URN of ships (Section 4.2), present current measures aimed at reducing ships' speed (Section 4.3), as well as explaining existing measures and initiatives that impact ship speed or have the potential do so (Section 4.4).

4.2 Existing[3] guidelines/frameworks/initiatives that address URN of ships

In 2014, the **IMO** adopted Guidelines for the Reduction of Underwater Noise from commercial shipping to address adverse impacts on marine life (MEPC.1/Circ.833). These guidelines describe steps to reduce noise emitted by commercial ships (Transport Canada, 2020). The guidelines will be revised with the aim 'to provide updated recommendations based on the latest developments in ship design and technology and to address the barriers to their uptake in an effort towards a significant and measurable reduction of underwater-radiated noise from ships' (IMO, 2022). A correspondence group is tasked with developing recommendations for the revision of the guidelines to be submitted to the Marine Environment Protection Committee (MEPC 80) in 2023. The Sub-Committee on Ship Design and Construction at their 8th meeting (SDC 8) noted that "the lack of international policies and noise pollution limit values had hampered progress towards the mitigation of noise pollution from ships" (SCC 8/18).

At the IMO level, sea areas can also be designated as Particularly Sensitive Sea Areas (PSSAs[4]) and, if approved as such, specific measures can be used to control the maritime activities in that area, such as routeing measures, strict application of MARPOL discharge and equipment requirements for ships, such as oil tankers, and the installation of Vessel Traffic Services (VTS) (IMO, ongoing a).

In Europe, two PSSAs are currently established: the Wadden Sea[5] in 2002 and Western European Waters in 2004[6] (IMO, ongoing a). France, Monaco, Spain and Italy are also in favour of the creation of a PSSA in the North-Western Mediterranean Sea (see MEPC

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[3] As of July 2022.

[4] See Resolution A.982(24) for the IMO guidelines for the identification and designation of PSSA.

[5] The Wadden Sea stretches from the Netherlands, past the river estuaries of Germany to its northern boundary in Denmark along a total coastline of some 500 km.

[6] The area covers the western coasts of the United Kingdom, Ireland, Belgium, France, Spain, Portugal, from the Shetland Islands in the North to Cape S. Vicente in the South, and the English Channel and its approaches.

77/INF.28) and France proposed that a restriction of vessel speed should be studied for this area too (Martin, 2021).

At the EU level, the Marine Strategy Framework Directive (2008/56/EC), known by the acronym MSFD, is in force. It requires Member States to set up national marine strategies to achieve or maintain good environmental status (GES) by 2020.

The MSFD identifies anthropogenic inputs of substance and energy into the maritime environment like underwater noises as pollution (EC, ongoing a). And Commission Decision (EU) 2017/848 specifies criteria for the assessment of the GES of this descriptor (D11):
- D11 criteria 1 — The spatial distribution, temporal extent, and levels of anthropogenic *impulsive sound sources* do not exceed levels that adversely affect populations of marine animals.
- D11 criteria 2 — The spatial distribution, temporal extent and levels of anthropogenic *continuous low-frequency sound* do not exceed levels that adversely affect populations of marine animals.

The Commissions Decision also requires Member States to establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities.

To date, this has led to guidelines on monitoring noise and to increased monitoring.

According to the evaluation of the implementation of the MSFD (EC, 2020), at the time of the evaluation only three Member States made a link to underwater noise in their MSFD programmes of measures and only 12% of the Member States were able to provide a conclusion on the current status of Descriptor D11. Only six countries expected to achieve good environmental status with respect to underwater noise by 2020.

The Technical Subgroup on Underwater Noise is currently developing a methodology for setting threshold values and EU threshold values for continuous sound are expected to be finalised by the end of 2022.

For a detailed overview of EU related (legal) developments, please see EMSA (2021) and EMB (2021).

In Canada, there are three underwater noise reduction initiatives ongoing in the Salish Sea, all coordinated by the ECHO Programme:
1. In the Haro Strait and Boundary Pass, ships are invited to voluntarily reduce their speed from the beginning of June to the end of November, when killer whales are present (Port of Vancouver, ongoing a).
2. From 1 June 1 to 31 October all tugboats transiting in the Canadian inshore area of the Strait of Juan de Fuca are requested to move south of the known killer whale feeding area if and when it is navigationally safe do so (Port of Vancouver, ongoing b).
3. A voluntary vessel slowdown trial is carried out at Swiftsure Bank from 1 June to 31 October 2022 (Port of Vancouver, ongoing c).

The first two initiatives started in 2018 and the third initiative in 2020.

Further, to assist shipbuilders and operators in reducing UNR from ships, some classification societies have developed voluntary class notations for ship noise (see EMSA (2021) for a recent overview). Vessels that are relatively silent can then be certified as such. Some seaports offer port fee reductions to vessels that are in possession of such a certificate (EMSA, 2021).

4.3 Existing measures aimed at reducing ship speed

Currently, there are a few speed reduction measures in place, some of which are voluntary and others that are mandatory.

Examples for voluntary measures are the Port of Los Angeles & Port of Long Beach Vessel Speed Reduction Programme ((The Port of Los Angeles, ongoing) (Port of Long Beach, ongoing)), which was established in 2001 to reduce air pollution from maritime shipping and a comparable programme that more recently has been implemented in South Korea (Ministry of Oceans and Fisheries, 2019) in order to reduce fine dust emissions from maritime shipping. Both programmes reward ships that actually slow down by providing discounts on certain port fees. And as part of the ECHO programme, several ship slow down initiatives in the vicinity of the Port of Vancouver have been implemented with the aim "to provide a better understanding of the cumulative effects of marine shipping on whales and inform the development and testing of potential threat-reduction solutions." (Port of Vancouver, ongoing d)

There are also examples for mandatory speed limits, such as speed limits for canals (Port of Amsterdam, 2020), ports or marine protected areas ((WaddenZee.nl, 2010), (Meijles, et al., 2021)). Regarding the latter, we are, however, not aware of mandatory speed limits applying to commercial ships sailing on main shipping lanes.

In busy shipping areas, Traffic Separation Schemes (TSS) are currently applied rather than mandatory speed limits, however, recommended speed limits can complement a TSS, as is the case in the Straits of Malacca, Singapore (INTLREG, 2019) and the Gulf of Panama (Canal de Panama, 2020).

For both existing voluntary and mandatory measures it holds that, if they apply to commercial shipping, they apply to limited geographical areas. And existing mandatory speed limits applying to commercial shipping have mainly been implemented for safety reasons.

4.4 Existing measures and initiatives potentially impacting ship speed

At the IMO level, the Energy Efficiency Design Index (EEDI) is in force. The EEDI is an energy efficiency measure implemented with the aim of improving the technical energy efficiency of newbuild ships. Newbuild ships of certain types and size segments need to meet EEDI requirements in terms of CO_2 per capacity mile from 1 January 2013 or 1 January 2015 on, depending on the ship type and size. The EEDI requirements become more stringent over time, also depending on ship type and size: the energy efficiency level that a newbuild ship attains has to be improved compared to a reference efficiency level and the reduction factors become more stringent over time. So far, four phases[7] with different stringency levels have been implemented (see Table 13 in Annex A for an overview of the required EEDI reduction factors, depending on ship type, size and phase).

[7] Phase 0 to Phase 3 have been implemented. Phase 4 stringency levels are still under discussion.

“One of the most effective ways of reducing the EEDI of a ship is to install a smaller main engine, thus reduce the ship’s design speed. Extensive speed reductions could though lead to unsafe underpowered vessels that may lose manoeuvring capability in adverse weather conditions. In order to avoid such scenarios, interim guidelines for determining minimum propulsions power to maintain manoeuvrability has been adopted by IMO (Resolution MEPC.232(65), as amended by resolutions MEPC.255(67) and MEPC.262(68)).” (Forsman, 2018)

The following two specific short-term measures were adopted by MEPC 76 in 2021:
1. A ship energy efficiency rating scheme based on the Carbon Intensity Indicator (CII) will be implemented for ships of 5,000 GT and above. Ships that rate D or E for three consecutive years will be required to submit a corrective action plan to show how the required index (C or above) would be achieved (IMO, 2021). In addition, administrations, port authorities and other stakeholders are encouraged to provide incentives to ships rated as A or B (IMO, 2021).
2. The Energy Efficiency Existing Ship Index (EEXI) will require existing ships of 400 GT and above to meet technical standards comparable to the EEDI requirements that already apply for newbuild ships. The reduction factors will be applied to the same EEDI reference efficiency levels, but the reduction factors will be lower, accounting for the fact that it is more difficult and costly to improve the energy efficiency of an existing ship (see Table 14 in Annex B for an overview of the required EEXI reduction factors, depending on ship type and size).

The amendments to MARPOL Annex VI required for the implementation of the two measures are expected to enter into force on 1 November 2022, with the requirements for EEXI and CII certification coming into effect from 1 January 2023. The first annual reporting would then be completed in 2023, with the first rating given in 2024 (IMO, 2021).

Regarding the EEXI, “EPL [Engine Power Limitation] is believed to be the easiest way for older ships to meet EEXI requirements because it requires minimal changes to the ship and does not change the underlying performance of the engine (MAN & PrimeServ, 2016). EPL establishes a semi-permanent, overridable limit on a ship’s maximum power and therefore speed (Andersen, 2017). For mechanically controlled engines, this would take the form of a mechanical stop screw sealed by a wire that limits the amount of fuel that can enter an engine. For newer, electronically controlled engines, EPL would be applied via a password-protected software fuel limiter. EPL would be overridable if a ship is operating under adverse weather conditions and requires extra engine power for safety reasons; in that case, the override should be recorded and reported to the appropriate regulatory authority (IMO, 2019c).” (ICCT, 2020)

If ships apply EPL, their attained EEXI is calculated, taking into account a main engine power of 75% MCR or 83% of the limited MCR whichever is lower (see Resolution MEPC.333(76)).

In addition to the regulatory requirements, there have also been initiatives to encourage a speed reduction of ships. BIMCO, for example, has developed charter clauses to overcome barriers to slow steaming in the charter market. A virtual arrival concept, to encourage ships to sail at a lower speed if they had to wait at a port anyway, has been developed. An online platform to facilitate this concept has also been developed (Blue Visby, ongoing).

4.5 Potential regulatory measure to reduce ships' speed in European waters

4.5.1 Current EU GHG policy framework for maritime shipping

In 2013, the European Commission set out its strategy to integrate maritime transport emissions in the EU GHG reduction policies (COM(2013) 479), which is a three-step strategy:
1. The implementation of a system that requires large ships using EU ports to monitor, report and verify their CO_2 emissions.
2. The definition of GHG reduction targets for the maritime transport sector.
3. The implementation of further measures, including market-based measures.

With the adoption of Regulation (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport in April 2015 (in short: EU MRV Regulation), the first step of this strategy was completed.

From January 2018 onwards, the Regulation requires companies to monitor fuel consumption, CO_2 emissions and other parameters for seagoing vessels above 5,000 gross tonnage (GT) on voyages to and from ports under the jurisdiction of a Member State and within these ports. From 2019 onwards, each year, companies have to submit an emissions report for each of their vessels falling within the scope of the Regulation. The emissions reports contain information on the *annual* CO_2 emissions and other relevant information for the entire reporting period (i.e. the previous calendar year) and this aggregated data is made publicly available.

No specific GHG reduction targets for the maritime transport sector have been set at the EU level, but in July 2021, the European Commission presented the Fit for 55 package, including several proposals for measures to reduce GHG emissions of maritime transport:
- FuelEU Maritime Regulation: A GHG intensity target for the energy used on board ships has been proposed together with, for certain ship types, mandatory use of onshore power at berth in EEA ports.
- Alternative Fuels Infrastructure Regulation: Requirements for Member States to ensure that sufficient infrastructure for the supply of alternative fuels will be provided have been proposed.
- EU Emissions Trading System: The CO_2 emissions of maritime shipping have been proposed to be included in the existing EU Emissions Trading System (EU ETS).
- Energy Taxation Directive: The introduction of minimum excise duties on the bunker fuels sold in EEA countries for the use on intra-EEA voyages has been proposed. A voluntary application to bunker fuel sold for the use on extra-EEA voyages is also part of the proposal.
- Renewable Energy Directive: A stricter GHG intensity target for transport fuels (independent of the specific sector) has been proposed together with a sub-target for advanced biofuels (EC, 2021).

While the proposed FuelEU Maritime Regulation and the proposed revision of the EU ETS system differ in some aspects, they both basically build on the framework as set by the EU MRV Regulation.

This means that the two proposed measures would:
1. Apply to ships above 5,000 GT.
2. Not apply to warships, naval auxiliaries, fish-catching or fish-processing ships, wooden ships of a primitive build, ships not propelled by mechanical means, or government ships used for non-commercial purposes.

3. Include only voyages that originate from or terminate in a port of call and that serves the purpose of transporting passengers or cargo for commercial purposes. A 'port call' is thereby defined as the port where a ship stops to load or unload cargo or to embark or disembark passengers. This means that certain ships' movements fall outside the scope, like extraction and carriage of dredged material or ice-breaking activities are exempt (for an overview see EU MRV FAQs (EC, ongoing b)).

What the two measures also have in common is that, in contrast to the EU MRV Regulation, only 50% of the extra-EAA voyages are covered. This means that only half of the CO_2 emissions emitted on these voyages would fall under the EU ETS and that only half of the energy consumed on these voyages would have to comply with the GHG intensity target.

4.5.2 Blue Speeds: preferred design options

A measure to reduce the URN of ships in EU waters and implemented in Europe can be designed in many different ways. In the following, the different, most relevant design elements are presented and discussed.

Mandatory versus voluntary measure

A measure to limit the speed of ships could be implemented as either a voluntary or a mandatory measure. There are different barriers that prevent ships from voluntarily decreasing their speed on a structural basis. These limiting factors are presented in the following, differentiating economic and logistical factors as well as institutional factors. Because of the different barriers as discussed below, Blue Speeds cannot be expected to be applied on a large scale on a voluntary basis. Therefore, Blue Speeds will only be effective if implemented as a mandatory measure. Some of the barriers mentioned below might thereby call for certain exemptions from the mandatory requirements or for more lenient requirements for certain segments, trades or voyages.

Blue Speeds will only be effective if implemented as a mandatory measure.
However, certain exemptions from the mandatory requirements or more lenient requirements for certain segments, trades or voyages should be considered.

Economic and logistical limiting factors

To avoid an efficiency loss due to slow steaming, the engine could be de-rated and other elements of the ships system could be re-optimised. This is associated with costs.

Reducing the speed of a ship can nevertheless be a cost-effective means to improve a ship's energy consumption. This means is not often applied on a voluntary basis due to competition in the shipping sector: if all competitors in the market reduced their speed, all competitors could potentially be better off due to lower fuel expenditures. However, you cannot expect that all competitors will adhere to the reduced speed if deviation, i.e., sailing at a relatively higher speed and offering a customer a shipment at a relatively lower transit time, gives you a competitive advantage over your competitors. This is why a market equilibrium in which slow steaming is applied on a voluntary, structural basis sector/segment-wide is unlikely to materialise. In the literature, this dilemma is referred to as the 'prisoner's dilemma'. What you see in practice then is that ships slow down during periods with relatively low freight rates and overcapacity and that they speed up again if freight rates are high and capacity is scarce.

If the overall time for the transportation increases due to the reduction of speed, there are several factors that reduce the incentive to slow down:

- When ships that are carrying cargo sail at a lower speed than usual, an adjustment of supply chains may be required to accommodate the slower speed of the vessels. Adjustment of supply chains is associated with additional transaction costs — the adjustment needs to be planned and requires organisational steps to be taken — and can also be associated with additional costs like extra financing costs or costs for the use of additional ships (for more details see Section 5.4.2). Should additional new ships be required, the building of these ships requires time. ‘Shipbuilding has very long lead production times, with a 2-3 years’ time lap between the ship’s contracting and delivery on average’ (Tknika, et al., 2020) even if there is no extra demand induced by additional policy measures.
- In certain markets, the different competing shippers are located are varying distances from the consignee. A current relative time disadvantage then seems to be compensated by other factors. If all ships are required to slow down, then the relative time disadvantage does not change, but the time disadvantage in absolute terms increases for those competitors located at a greater distance which could lead to a loss of market share.
- An increase in transit time could be problematic for certain types of cargo. For example, goods that are perishable might suffer a loss of quality if their transit time is increased.
- In general, refrigerated cargo ships might, compared to other ship types, profit less from a speed reduction. For these ship types it holds that the energy demand of the cooling systems is relatively high and while slow steaming reduces the energy consumption of the ships’ main engines, the cooling system’s energy consumption is not reduced, but rather increased by longer transit times.
- If ships slow down, passengers or shippers may prefer to use other modes of transport than ships, thereby avoiding the longer transportation time. For example, ferry passengers or shippers of high-value cargo may then prefer air transport, cargo transported by short sea shipping might be transported by road instead and cruise passengers may prefer another type of holiday if the voyage time increases. If modal shifts occur due to a reduction of ships’ speed then this might not only lead to a loss in the maritime shipping sector, but also to an increase in emissions.
- Slow-steaming can be an economic issue and difficult in practical terms for small passenger ships and small mixed passenger-cargo vessels (World Maritime University, 2021). These vessels can constitute a lifeline for, for example, connections to/from and between islands. The increased transit times, due to lower speeds, can result in a change of schedules and potentially less transits per day if no extra ships are used. If this puts profitability at risk, operators could withdraw and connections could get lost if not subsidized.

Institutional limiting factors

Some ships are owned and operated by the same entity, whilst others are owned and operated by different entities. Chartering of ships is common practice in the sector, with the owner and charterer concluding a ‘charter party’. The conditions of these charter parties can discourage/prevent the charterer from operating the ship at a lower speed, even if a ship has to wait at a port. ‘First come, first served’-policies applied by ports also play a discouraging role in this context.

Alternative charter parties have been agreed in the past to facilitate slow steaming (BIMCO, 2011; 2012; 2013) and the ‘virtual arrival concept’ has been developed to tackle these issues, but we are not aware of a broad application thereof.

Level of implementation of measure

A measure that reduces the URN of ships in European waters can be implemented at different levels, i.e. at the global, at the regional (EEA, EU or smaller regions), at the national or at the local level.

A measure implemented at the global level could follow the targeted approach of Particularly Sensitive Sea Areas (PSSAs) or Emission Control Areas (ECAs). This means that, at the IMO level, specific areas could be designated as PSSA or ECA and that the regulation applied to these areas would follow a global common framework. Or a generic global approach could be followed, requiring ships, independent of their routes, to reduce their speed. The latter has been discussed at MEPC as a potential short-term measure to reduce the sector's GHG emissions, but has not been implemented as such. Both global approaches are however not relevant in the context of this study, which focusses on measures implemented in the EU.

In general it holds that, the higher the implementation level of a measure, the less markets can be expected to be distorted and the more effective a measure potentially is. To give an example: if a country unilaterally implemented a mandatory speed limit for all ships calling at the country's seaports, then ships will probably avoid the measure by calling at a port in a neighbouring country. This would reduce the environmental effectiveness of the measure: the ships avoiding the measure would not slow down and the distance to be covered by hinterland transport would probably increase. In addition, the measure would lead to a competitive disadvantage for the ports located in the country implementing the regulatory measure. Implementation at EEA/EU+UK level is thus to be preferred over implementation at sublevels. A collaboration of countries with competing ports is also conceivable.

Options that Member States can reasonably unilaterally implement are therefore also limited. Environmental requirements as part of public procurement (e.g. for ferries) and environmental requirements for public fleets (e.g. patrol boats) are examples in this context. These options could be included in a guidance document to be worked out in the context of the EU Marine Strategy Framework Directive.

Blue Speeds can, for competitive reasons, can best be implemented at the highest possible level which means that implementation at EEA/EU+UK level is to be preferred over implementation at a sublevel. A collaboration of countries with competing ports is also conceivable.

Legal feasibility of regulated slow steaming at EU level

As part of the Faber, et al.(2012) study, the legal feasibility of imposing regulated slow steaming on ships sailing to EU ports, with the aim of reducing the climate impact of the ships and/or reducing the air pollution around ports, have been analysed. This legal analysis concludes that mandatory slow steaming measures for the purpose of reducing atmospheric pollution and GHG emissions:
- are within the competence of the EU;
- will probably not be considered inconsistent with the following principles of customary international law and of UNCLOS:
  - the principle that each State has complete and exclusive sovereignty in its territorial and internal waters;
  - the principle that no State may validly purport to subject any part of the high seas to its sovereignty;
  - the principle which guarantees freedom of navigation in the high seas.

Only a fourth principle, i.e. the exclusive jurisdiction of the flag State in respect of its vessels' activities in the high seas, could still be brought before the European Court of Justice. However, there seems to be no interference with the exclusive jurisdiction of the flag State by the imposition of mandatory slow steaming as a condition for entry.

The overall conclusion drawn is therefore as follows:
"In our view the EU Member States have the right to prescribe mandatory slow steaming as a condition for entry not only in respect of voyages ending or starting from an EU Member State's port but for all voyages that a ship that enters their port performs. However, there are arguments against exercising such rights where there is no connection between the voyage the foreign ship performs and the EU. These, in essence are:
a) that the State of departure, the State of destination and the flag State are better placed to regulate the behaviour of the foreign ship during such voyages;
b) that the enforcement would be more problematic."

Please note, however, that whether the same conclusions can be drawn for a speed limit implemented with the main aim of reducing URN of ships still needs to be analysed.

From a legal perspective, Blue Speeds can best be implemented as a condition for entry into Member States ports.

Geographical scope of the measure

The geographical scope of the measure is an important design element and there are two main options in this regard. A targeted approach could be followed, applying a speed limit to specific vulnerable areas or, alternatively, a generic approach could be followed, applying a speed limit to voyages to/from EEA ports independent of the specific marine environment that the ships transit on their routes.

For speed limits implemented to avoid ship strikes, it makes sense to restrict the geographical scope to critical habitat areas of whales. These speed limits can potentially also be dependent on the corresponding season.

The most promising enforcement mechanism of a speed limit is if compliance with the speed limit is considered to be a condition on entry into port. Port State Control would then refuse non-compliant ships entry into the ports of a Member State. This, however, restricts the enforcement of a speed limit to vulnerable areas and implementation at EU level difficult/ineffective unless most ships passing this area call at an EU port or unless these vulnerable areas are located within territorial waters of an EU country.

In principle, speed limits implemented with the aim of reducing the URN impacts of shipping on the broader marine environment, could also take into account the distribution of species known to be vulnerable to shipping noise and be restricted to these areas. However, this relies on data that are frequently not available, are operationally complex and also may conflict with optimisation for other purposes, including minimizing GHG emissions (Leaper, 2019).

If the geographical scope of the latter was limited, then a limitation to busy/highly frequented shipping routes could be an option. A major disadvantage of a regionally restricted speed limit is, however, that ships might speed-up after having transited the area in which the speed limit holds, potentially leading to higher noise levels, GHG emissions and air pollution outside the regulated area. A broader geographical application of a speed limit is therefore preferable.

If the generic approach of applying a speed limit to voyages to/from EEA ports independent of the specific marine environment that the ships transit on their routes is implemented, then the speed limit could apply to:
- intra-EEA voyages; and/or
- incoming extra-EEA voyages; and/or
- outgoing extra-EEA voyages.

The speed reduction potential on intra-EEA voyages is probably lower than for extra-EEA voyages, at least with regard to coastal shipping for which the average current speed can be expected to be relatively low. In addition, ships that solely sail on intra-EEA routes can be expected to be relatively small and thus produce relatively less URN. On the other hand, traffic density can be relatively high on intra-EEA voyages, leading to relatively high URN levels and thus increasing the potential added value of a speed limit. In addition, ferries and Ro-pax vessels mainly sail on intra-EEA voyages and these are vessels which sail at a relatively high speed. And there are also large vessels for which an intra-EEA voyage is only part of a longer voyage, such as large container ships coming from Asia which call at more than one EEA port.

From an environmental point of view, the inclusion of 100% of the incoming and outgoing extra-EEA voyages is, in principle, the most effective option. The current EU policy proposals for the reduction of GHG emissions of maritime shipping (FuelEU Maritime Regulation, Revision of EU ETS Directive), however, only include 50% of the incoming and the outgoing extra-EEA voyages. This leaves scope for other regional measures which could potentially cover the other 50% of the voyages. At the same time, the political acceptability might be higher compared to a 100% inclusion, due to the lower compliance costs. However, as already mentioned, ships might speed-up on the second half of the voyage, potentially leading to even higher noise levels, GHG emissions and air pollution on this part of the voyage.

Regarding enforcement, a speed limit on incoming extra-EEA voyages might, in practice, be easier to implement compared to a speed limit on outgoing extra-EEA voyages but, on the other hand, inclusion of in- and outgoing voyages seems to be legally possible (at least in the context of GHG emission reduction and air pollution) and if only incoming voyages were regulated this could be taken as a one-sided trade barrier to the exports of non-EEA countries.

Blue Speeds can best be applied to 100% of intra- and extra-EEA, incoming and outgoing, voyages.

An analysis of the 2018 EU MRV fleet[8] shows (see Table 1) that, at the fleet level, around 6% of the ships have been active on intra-EEA voyages only, while around 22% of the ships have been active on extra-EEA voyages only and around 71% of the ships have been active on both. These percentages, however, differ highly between ship types. Especially Ro-pax ships (82%), but also Ro-ro ships (42%) and container/ro-ro cargo ships (21%) had a relatively high share of ships that solely sailed on intra-EEA routes. For almost all ship types (except LNG carriers), the vast majority of ships that sailed on extra-EEA voyages sailed on both extra-

[8] Ships of 5,000 GT and above sailing to and from EEA ports, transporting cargo or passengers for commercial purposes.

and intra-EEA routes. The number of ships that sailed on extra-EEA incoming routes is about the same as the number of ships that sailed on extra-EEA outgoing routes; this applies at the fleet level as well as the ship type level.

Table 1 - 2018 EU MRV fleet: per ship type, the distribution of the number of unique ships over type of voyage

# of ships active on…	…intra-EEA voyages only	…extra-EEA voyages only	…both intra- and extra-EEA voyages
Bulk carrier	1%	33%	66%
Chemical tanker	4%	11%	84%
Combination carrier	0%	30%	70%
Container ship	5%	12%	84%
Container/ro-ro cargo ship	21%	1%	78%
Gas carrier	9%	32%	60%
General cargo ship	2%	11%	87%
LNG carrier	1%	78%	20%
Oil tanker	4%	29%	67%
Passenger ship	3%	1%	95%
Refrigerated cargo carrier	0%	34%	66%
Ro-pax ship	82%	4%	13%
Ro-ro ship	42%	5%	54%
Vehicle carrier	3%	4%	93%
Total (including 'other ship types')	**6%**	**22%**	**71%**

At fleet level, the energy consumption/CO_2 emissions of ships falling under the EU MRV Regulation (see Table 2), which gives an indication for the activity of the ships, are roughly evenly distributed over the intra-EEA (32%), incoming extra-EEA (32%) and outgoing extra-EEA voyages (29%). Naturally, for ship types of which a relatively low percentage of ships sailed on intra-EEA voyages only (e.g. refrigerated cargo carriers, bulk carries, LNG carriers) and a relatively high share of ships sailed on intra-EEA voyages (e.g. Ro-pax ships), the percentages deviate from these averages.

Table 2 - 2018 EU MRV fleet: per ship type the distribution of CO_2 emissions over type of voyage and ports

CO_2 emissions	Intra-EEA voyages	Extra-EEA incoming voyages	Extra-EEA outgoing voyages	In port
Bulk carrier	12%	47%	37%	4%
Chemical tanker	28%	33%	28%	10%
Combination carrier	16%	34%	40%	11%
Container ship	26%	37%	33%	4%
Container/ro-ro cargo ship	46%	25%	21%	10%
Gas carrier	23%	34%	33%	7%
General cargo ship	31%	32%	32%	5%
LNG carrier	6%	45%	46%	3%
Oil tanker	16%	38%	36%	11%
Passenger ship	70%	9%	9%	11%
Refrigerated cargo carrier	9%	51%	38%	3%
Ro-pax ship	84%	4%	4%	8%
Ro-ro ship	68%	14%	16%	5%
Vehicle carrier	30%	31%	34%	6%
Total (including 'other ship types')	**32%**	**33%**	**29%**	**6%**

Ship types/sizes and activity of ships

In Section 4.5.1, the ship types, sizes and activities that are proposed to fall under the FuelEU Maritime Regulation and the revised EU ETS have been presented. These are in line with the scope of the EU MRV Regulation.

A speed limit that applies the same scope is probably the easiest to implement and the application to new and existing ships also makes sense in the Blue Speeds context. There are, however, reasons why it might be better to deviate from this scope for the purpose of Blue Speeds.

From an environmental point of view, the exemption of ship voyages not serving the purpose of the transportation of cargo and passengers for commercial purposes and the exemption of fishing vessels is not meaningful. Including ships smaller than 5,000 GT could also be effective, since the administrative costs, at least for the shipping companies, can be expected to be less than for fuel/emissions monitoring.

The following potential exemptions could, for example, be more useful in the context of Blue Speeds (see also discussion of barriers to voluntary slow steaming as presented above):
- Ships that have been classified as being relatively silent when sailing at their design speed could be exempt.
- Laden voyages of ships transporting perishable goods over long distances could be exempt.
- Single ships for which the energy consumption would demonstrably and structurally be higher when complying with Blue Speeds, could be subject to more lenient requirements.

With regard to small ships, it should however be kept in mind that, should AIS data be used for enforcement purposes, SOLAS currently requires the following ships to be equipped with AIS transponders:
- all ships of 300 GT and upwards engaged on international voyages;
- cargo ships of 500 GT and upwards not engaged on international voyages;
- all passenger ships irrespective of size.

The EU (DIRECTIVE 2011/15/EU) also requires fishing vessels of more than 15 metres to be equipped with an AIS transponder.

This requirement could be extended to smaller ships in the future, but since the length of ships seems to be an important determinant for a ship's URN (Vancouver Fraser Port Authority, 2020), exempting the smallest ships might also be reasonable from an environmental point of view.

Blue Speeds should apply to new and existing ships and, by default, to all types and sizes of ships and all types of voyages. Small ships should be included as far as reasonable, in view of the environmental benefits and the administrative costs.

Maximum versus average speed limit

A speed limit could be implemented as a limitation of the maximum speed or the average speed of ships. For road traffic, for instance, maximum speed control is well known, but an increasing number of countries also apply section speed control, controlling the vehicles average speed on certain route segments.

To reduce the probability of ship strikes, a limitation of the maximum speed of ships is clearly more relevant than a restriction of ships' average speed.

A limitation of the average speed of ships can potentially contribute to a reduction of the probability of ship strikes and ships' URN impact on the marine environment. However, the effect would be more uncertain, given that ships will sail at an above-average speed on certain, unknown parts of the route. A limitation of the maximum speed is thus preferable from an environmental point of view.

Regarding the enforcement of a speed limit of ships, the average speed of a ship is relatively easy to monitor, applying section speed control comparable to road transport. Ships could, just as road transport, be monitored by means of fixed radar control measure points, but departure and arrival time at ports as monitored and reported (e.g. due to the EU MRV Regulation) or AIS data collected at two points on a ships' route seem to be better suited for the sector.

For the enforcement of a maximum speed level, spot checks of AIS data could be carried out, but such spot checks might not be an effective way of detecting violations of the maximum speed. A limitation of the engine power output of ships, as proposed for the EEXI measure, would probably be much more effective. Here it only has to be ensured that the override functionality, which may be used in case more power is required for safety reasons, is not used structurally. It might, however, be legally more challenging for the EU to implement technical requirements for ships as compared to operational requirements, since technical requirements for ships are normally implemented at IMO level. The United States, however, unilaterally imposed double hull requirements for oil tankers following the Exxon Valdez oil spill before the IMO implemented corresponding requirements on a global level, which could be considered as a precedent in this context.

Blue Speeds should ideally be implemented as a limit to the maximum speed of ships.

Speed over ground versus speed through water

The speed of a ship can be measured by means of two different units, speed over ground (SOG) and speed through water (STW). SOG varies depending on environmental conditions. For example, with the current ahead, SOG decreases whereas with the current from astern, SOG increases. In contrast, STW is independent of the environmental conditions. STW is more highly related to the engine load and thus more relevant in the context of a ship's energy consumption and GHG emissions. STW is also the unit that is relevant in the context of URN of ships. One of the outcomes of the ECHO programme is that speed through water is an important determinant for a ship's URN.[9]

In the context of ship strikes, STW or SOG can be relevant, depending on how the ship and the whale move in relation to each other. For example, the seasonal speed limit recommended by the IMO in parts of the Gulf of Panama is monitored in terms of SOG (<10 knots SOG) (Guzman, et al., 2020), but this could be due to the fact that SOG is much easier to monitor than STW.

[9] "The updated Phase 2 statistical model confirmed that vessel size, speed through water, and vessel draft remain the strongest correlators to underwater radiated noise, and that propeller RPM may also be strong indicator." (Vancouver Fraser Port Authority, 2021).

SOG is easier to monitor, since both AIS and GPS data can provide ships' SOG. STW is documented on ships on a daily basis in the noon report, however this consists of only one data point per day (IMO-GloMEEP & GIA, 2018). Vessel performance monitoring systems could be installed on board ships to provide STW data at regular intervals (see for example (VPO, 2019)), but these systems are not installed by default.

If an engine power output limitation of ships, as proposed for the EEXI measure, was and can be prescribed at the EU level, then monitoring of ships' STW would not be required.

Blue Speeds should ideally be implemented as a limit of ships' speed through water and by a corresponding limitation of ships' engine power output. If this is not feasible, a speed limit in terms of speed over ground would be required.

Uniform/differentiated speed limit

Given the variety of ship types and their design speeds, a uniform speed limit, prescribing a uniform maximum speed for all ship types, can be considered unrealistic and unreasonable (see also TNO (2021)).

To prevent ship strikes, a uniform critical speed limit is however probably more relevant and could be implemented for restricted geographical areas. A reduction of the current speeds of the ships, even if differentiated per ship type, can also contribute to a reduction of ship strikes if at least some ships sail slower than the critical speed as a result.

The speed limits could, if differentiated, be differentiated per individual ship, applying a 75% factor to the ships' individual design speeds. This, however, would lead to high administrative costs for monitoring. It is much easier to implement one specific limit in terms of knots which applies to a specific ship type and size category.

Blue Speeds should be implemented, applying differentiated speed limits, depending on the ship type and size category.

Level of speed limit

The level of the speed limit should be chosen such that the implementation is technically possible, that no adverse environmental effects accrue, and that Blue Speeds are economically viable.

There is a technological limit to speed reduction, depending on the ship's engines. Reducing a ship's speed below a certain 'minimum speed', where the engine is operated at a relatively low engine load, is not only associated with poorer energy efficiency, but it is also associated with the risk of higher engine maintenance requirements as well as the risk of potentially damaging the engine. This minimum speed limit differs from ship to ship, also depending on how many engines the ship is equipped with (Jivén, et al., 2020).

We consider a limitation of the maximum speed of ships at 75% of the design speed of the ships, resulting in a maximum engine load of approximately 36% of the Maximum Continuous Rating, as an appropriate limit for Blue Speeds. Most engines are able to operate at this level of reduced power without significant adverse effects, whereas "[s]ailing at power rates lower than 36% of MCR will not always be technically possible, as it could damage the engines.” (TNO, 2021) At the same time, sailing at 75% of the design speed will be very beneficial for the environment. The social cost-benefit analysis as presented in the following, will show that, if Blue Speeds are implemented at this level, Blue Speeds lead to net positive environmental effects for all ship type/size categories affected and can be cost-effective for the sector, depending on the bunker fuel price. The implementation of Blue Speeds as a limitation of the maximum speed at 75% of ships’ design speed is therefore considered an ambitious, but feasible option.

Should single ships, however, be technically and verifiably unable to comply with this limit or if their energy consumption would be demonstrably and structurally higher when complying with Blue Speeds, more lenient requirements should be applied by way of an exemption. Such exemptions should be considered especially where the speed limits were not determined based on the ships’ individual design speeds, but on the average design speed of a ship/size category (for a discussion of the baseline, please see below in this subsection).

The implementation of Blue Speeds as a maximum speed limit at 75% of ships’ design speed is considered an ambitious, but feasible option.

Baseline

When determining the speed limits for the different ship types and sizes, the reference value, i.e. the assumed design speed to which the 75% factor would be applied to determine the actual speed limit, is a very crucial element. In this context, it is important to find a balance between the effectiveness of the measure, the technical feasibility and the treatment of early adopters of energy saving measures.

Due to the EEDI, ships with a relatively low design speed might, for example, have been ordered, and to require an additional 25% reduction of the design speed on top of this could be considered an unreasonable punishment of early adopters of slower ship speeds. Working with an average baseline value for new and existing ships for the different ship type/size categories helps in this context, but compliance with the resulting speed limit should then also be technically feasible for existing ships too.

The Blues Speed limits should be determined based on carefully chosen baseline design speed values.

Summary of preferred design of Blue Speeds

Blue Speeds
1. should be implemented as a mandatory measure.
2. can best be implemented at the highest possible level: implementation at the EEA/EU+UK level is preferrable. A collaboration of countries with competing ports is also conceivable.
3. can best be implemented as a condition for entry into member state ports.
4. can best be applied to 100% of intra- and extra-EEA, incoming and outgoing, voyages.
5. should be implemented by applying differentiated speed limits, depending on ship type and size category.
6. should apply to new and existing ships and, by default, to all types and sizes of ships and all types of voyages.

7. should ideally be implemented as a limit to the maximum speed of ships. The implementation of Blue Speeds as a maximum speed limit at 75% of ships' design speed is considered an ambitious, but feasible option. More lenient requirements for individual ships might be appropriate.
8. should ideally be implemented as a limit of ships' speed through water and by a corresponding limitation of ships' engine power output. If this is not feasible, a speed limit in terms of speed over ground would be required.
9. And speed requirement levels should be determined based on carefully chosen baseline design speed values.

4.5.3 Blue Speeds: implementation

If Blue Speeds were implemented as an EU Regulation, the highest level of harmonisation between Member States and the broadest application could be achieved. An EU Directive would achieve the same broad application, but would require Member States to develop national laws for the implementation of the Directive which means that more time is required for the overall implementation.

A Regulation/Directive for the implementation of Blue Speeds could have been proposed and implemented as part of the Fit for 55 policy package, since the package includes different measures that aim to reduce GHG emissions of maritime transport and since Blue Speeds not only reduce URN, but also the GHG emissions of the sector. Given that the negotiations of these policy proposals are in full progress, the moment for the potential integration of a Blue Speeds Regulation/Directive can however be considered as having passed.

An integration of Blue Speeds into the FuelEU Maritime Regulation or the revised EU ETS Directive is conceptually not straight forward, which is why, should these proposals be implemented, integration at a later stage, i.e. when revised, is also not obvious. Should, however, the implementation of the revised EU ETS Directive fail and the maritime shipping sector is not included in the EU ETS, then Blue Speeds could be brought forward as an alternative.

Otherwise, Blue Speeds could be implemented through the Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC). This will depend on threshold values for Good Environmental Status with respect to continuous underwater sound set under MSFD descriptor 11 and the spatial and temporal extent over which sound levels exceed these threshold values. The MSFD is currently under revision with Commission adoption planned for the first quarter of 2023 (see EC (2021) for more information).

As already mentioned above (see Section 4.2) the MSFD requires EU countries to develop marine strategies in order to achieve a 'good environmental status' for 11 descriptors. One descriptor (D11, criteria 2) is related to anthropogenic continuous low-frequency sound.

In the first instance, the Member States are obliged to develop individual programmes of measures, but the Directive also aims at coordination and harmonisation among Member States and third countries, given the transboundary nature of the marine environment. The MSFD points to the four established European Regional Sea Conventions[10] which can play an important role in this context.

The MSFD also requires a regular update of the marine strategies.

[10] OSPAR Convention, Helsinki Convention, Barcelona Convention, and Bucharest Convention.

As explained above (see Section 4.5.2, subsection ‘Level of implementation of measure’), individual Member States cannot, for competitive reasons, be expected to unilaterally implement mandatory Blue Speeds. It is, however, conceivable that different Member States, especially Member States with competing sea ports, make a coordinated joint decision to implement mandatory Blue Speeds as part of their marine strategies. Compared to an EU Regulation, this approach requires a higher effort from the countries involved and it would also have to be clarified whether mandatory Blue Speeds are within the competence of a subset of Member States European Regional Sea Conventions.
As an alternative, recommendations for community action (see MSFD, Article 15) for the implementation of Blue Speeds at the EU level could be developed and submitted to the European Commission.

As will be explained in more detail in Section 5.4.2, an adaptation of port logistics can play an important role in minimizing the costs involved in adjusting supply chains that potentially accrue due to Blue Speeds. To facilitate a corresponding adjustment, an EU Guidance could also be developed in the context of the MSFD.

Finally, Directive 2005/35/EC incorporates international standards for ship-source pollution (MARPOL 73/78 Annex I and MARPOL 73/78 Annex II) into European Community law and wants to ensure that persons who are responsible for ship-source discharges of polluting substances are subject to adequate penalties. The substances covered are oil and noxious liquid substances in bulk.

URN, above a certain limit, can, in principle, also be considered a ship-source discharge of a polluting substance, and according infringements could be penalized. This would however mean that a goal-based approach is followed in the sense that not a speed limitations would be implemented, but that ships could decide on how to meet the URN limit. This gives ship owners/operators more flexibility, but on the other hand monitoring and enforcement can be expected to be much more complex.

5 Social cost-benefit analysis

5.1 Introduction

In the previous chapter, the preferred design of Blue Speeds is presented. In a second step, the measure is assessed by means of a social cost-benefit analysis as will be described below.

The study thereby follows an anthropogenic approach, which means that the benefits of the measure are assessed from a human perspective. Impacts on the intrinsic value of nature, independent of human benefits, have thus not been considered. To give an example: if, due to the speed limit, less ship strikes occur, it is not the fact that the life of a whale has been saved that is considered as such, but the benefits to humans as a result of saving the life of the whale. This is a common approach for social cost-benefit analyses, since the intrinsic value of nature is very difficult to determine.

The different costs and benefits considered in the social cost-benefit analysis are as follows and will be presented in detail below.

The potential benefits considered are:
- impact on URN (Section 5.3.1);
- impact on energy consumption and fuel expenditures (Section 5.3.2);
- impact on climate change due to a reduction of CO_2 emissions (Section 5.3.3);
- impact on health and environment due to a reduction of air pollution (Section 5.3.4).

The potential costs considered are:
- engine modification costs for existing ships (Section 5.4.1);
- costs associated with additional ship capacity (Section 5.4.3);
- additional financing costs for cargo (Section 5.4.4).

Potential costs associated with an adjustment of supply chains are discussed in qualitative terms in Section 5.4.2.

Please note that the reduction of Blue Speeds on URN can be expected to have a positive impact on the marine environment and therefore also on humans (e.g. positive effect on fishing industry). A quantitative assessment of these effects is however very complex and outside the scope of the study.
Please note also that data availability does not allow the assessment of the full potential of Blue Speeds — while Blue Speeds have been proposed to apply to all ship types and sizes and to all types of voyages, data is only available for the EU MRV fleet, i.e. for ships above 5,000 GT, for voyages serving the purpose of transporting passengers or cargo for commercial purposes and not for fishing vessels.

Before the benefits and costs of Blue Speeds are discussed in Sections 5.3 and 5.4, the modelling approach and data used are presented (Section 5.2). Section 5.5 presents the outcomes of the social cost-benefit analysis.

5.2 Modelling approach and data used

5.2.1 Baseline fleet

The European Commission provides EU shipping fleet data in the context of the EU MRV Regulation (see Section 4.5.1 for details). In the Commission's '2019 Annual Report on CO_2 Emissions from Maritime Transport' (see Appendix 2, Table 3 of that report), the average speed[11] and the average design speed[12] are specified for 45 ships size and ship type categories for 2018. The starting point of the analysis is the 2018 EU MRV fleet as presented in that report.[13] The Commission has also published data for 2019 and 2020, however, this does not include the average speed per ship type/size. Working with the 2018 data also allows data to be complemented, where necessary, with data from the Fourth IMO GHG Study.

For some of the ship types. The Commission's 2019 report only provides speed data for one size category and for some ship types, and the average speed has not been specified. We therefore complemented the data with EU MRV data as published by EMSA at a later stage (EMSA, 2022).

The main characteristics of the baseline fleet as considered in the study is presented in Table 3. Please note that the average speed in the baseline has not been corrected for a potential impact of the EEXI requirements and the potential inclusion of maritime shipping in the EU ETS. Please note also that the characteristics of the baseline fleet as presented in Table 3 deviate slightly from data on the EU MRV 2018 fleet published by the Commission after the publication of the 2019 Annual Report.

Table 3 – Main characteristics of baseline fleet

Ship type	Size category	Unit	Total # vessels	Total 2018 CO_2 emissions (EU MRV scope) in megaton	Average 2018 speed (knots)
Bulk carrier	0-9,999	dwt	32	0.13	9.2
Bulk carrier	10,000-34,999	dwt	675	2.60	10.3
Bulk carrier	35,000-59,999	dwt	1,229	4.20	10.6
Bulk carrier	60,000-99,999	dwt	1,301	6.30	10.8
Bulk carrier	100,000-199,999	dwt	379	2.60	9.6
Bulk carrier	>=200,000	dwt	25	0.20	10.9
Chemical tanker	0-4,999	dwt	1	0.02	9.4
Chemical tanker	5,000-9,999	dwt	100	0.63	10.6
Chemical tanker	10,000-19,999	dwt	370	2.00	10.6
Chemical tanker	>= 20,000	dwt	1,229	6.50	10.7
Container	0-999	TEU	168	2.10	12.2
Container	1,000-1,999	TEU	302	3.60	11.7
Container	2,000-2,999	TEU	222	4.10	13.4
Container	3,000-4,999	TEU	265	6.70	14.5
Container	5,000-7,999	TEU	233	6.40	15.1

[11] Under the EU MRV Regulation, shipping companies have to report the distance travelled by their ships as well as the 'time at sea'. This allows the ships' average speed to be determined.

[12] Referred to as 'service speed'.

[13] Please note in this context, that the 2018 data as published by the Commission in 2020 can deviate from updates published by the Commission at a later stage. We do not expect, however, that these changes will impact the main conclusions of the study.

Ship type	Size category	Unit	Total # vessels	Total 2018 CO_2 emissions (EU MRV scope) in megaton	Average 2018 speed (knots)
Container	8,000-11,999	TEU	266	8.20	15.4
Container	12,000-14,499	TEU	143	5.00	15.9
Container	>=14,500	TEU	145	8.00	16.5
General cargo	0-4,999	dwt	13	0.04	11.9
General cargo	5,000-9,999	dwt	407	1.60	10.0
General cargo	>=10,000	dwt	764	4.20	11.1
Liquefied gas tanker*	0-4,999	cbm	0	0.00	9.3
Liquefied gas tanker	5,000-9,999	cbm	3	0.02	10.0
Liquefied gas tanker*	10,000-19,999	cbm	0	0.00	11.8
Liquefied gas tanker*	20,000-59,999	cbm	0	0.00	12.2
Liquefied gas tanker	60,000-79,999	cbm	1	0.04	13.8
Liquefied gas tanker*	80,000-119,999	cbm	0	0.00	14.0
Liquefied gas tanker	120,000+	cbm	203	6.07	14.0
Oil tanker	0-4,999	dwt	1	0.05	5.6
Oil tanker	5,000-9,999	dwt	37	0.18	7.0
Oil tanker	10,000-19,999	dwt	19	0.48	10.6
Oil tanker	20,000-59,999	dwt	160	3.80	10.1
Oil tanker	60,000-79,999	dwt	198	1.30	10.7
Oil tanker	80,000-119,999	dwt	508	6.10	9.7
Oil tanker	120,000-199,999	dwt	366	4.20	10.0
Oil tanker	>=200,000	dwt	121	1.70	11.3
Other liquids tankers	All sizes	dwt	10	0.16	14.1
Refrigerated cargo	All sizes	dwt	135	1.80	16.6
Cruise	2,000-9,999	GT	8	0.05	10.7
Cruise	10,000-59,999	GT	56	1.43	10.9
Cruise	60,000-99,999	GT	48	2.77	13.4
Cruise	>=100,000	GT	32	2.33	13.2
RoPax	2,000-9,999	GT	57	1.07	19.63
RoPax	10,000-59,999	GT	312	13.34	17.21
RoPax	60,000 +	GT	6	0.40	16.49
Ro-Ro cargo	5,000+	GT	252	6.00	12.0
Vehicle	All sizes	GT	534	5.00	14.6
Gas carrier	All sizes	GT	309	2.60	10.60
Total all vessels	**All sizes**	**-**	**11,676**	**135.99**	**11.63****

* No vessels appear to have reported in this category.

** Fleet weighted average speed.

We estimated the total SO_x and NO_x emissions for the baseline fleet as presented in Table 4.

Table 4 - Baseline air pollutants from maritime transport in the EU MRV in 2018 (tonnes)

Air pollutant	Baseline emissions
SO_x	343,000
NO_x	3,304,000

Since the potential speed limit will be implemented after the stricter IMO sulphur limit came into effect (2020), this stricter sulphur limit (0.5% m/m sulphur content in fuels used outside ECAs) has been considered for the estimation of the baseline SO_x emissions.

In the following section, ship type/size categories that would be required to reduce their speed if the maximum speed of ships was restricted to 75% of their design speed will be identified.

5.2.2 Speed reduction potential of Blue Speeds

For the baseline fleet, as presented in the previous section, we have determined the speed reduction potential of Blue Speeds.

A maximum speed limit set at 75% of the design speed is thereby considered[14]. The speed data available for the EU MRV fleet is for the average and not the maximum speed of the ships which is why, to determine the effect of Blue Speeds, we have to translate the maximum speed limit into the resulting average speed of the ships. In practice, vessels will sail on average slower than this maximum speed limit – ships can be expected to sail as far as possible at the maximum speed, but when approaching ports, ships will naturally have to slow down. To account for this fact, we applied a rough correction factor, assuming that the ships will sail at an average speed of 70% of the design speed if a maximum speed of 75% of the design speed was implemented.
Under this assumption, 29 out of the 49 vessel type/size categories differentiated would have to reduce their speed if Blue Speeds were implemented (see Table 5). On average, the average speed would have to be reduced by around 5% at the fleet level, with the highest *relative* speed reduction potential (more than 10% reduction) for medium-sized chemical tankers, largest container ships, small general cargo ships, refrigerated cargo ships and Ro-Pax ships of all sizes.

The 29 categories which would need to reduce their speed comprise more than 8,000 vessels from the around 11,700 vessels in the EU MRV fleet considered in the study.

In Table 5, the ship categories which would be required to reduce their speed if the above described speed limit was applied are given. Table 5 also lists, per category, the total number of vessels, the specific speed reduction potential in percentage[15] and the corresponding reduction range.

Table 5 - Speed reduction potential of Blue Speeds determined for the EU MRV 2018 fleet (max. speed limited to 75% of design speed, resulting in average speed of 70% of design speed)

Ship type	Size category	Unit	Total # vessels in baseline	Specific speed reduction potential	Speed reduction potential range
Bulk carrier	0-9,999	dwt	32	8.62%	5-10%
Bulk carrier	10,000-34,999	dwt	675	5.10%	5-10%
Bulk carrier	35,000-59,999	dwt	1,229	5.89%	5-10%
Bulk carrier	60,000-99,999	dwt	1,301	7.14%	5-10%
Bulk carrier	100,000-199,999	dwt	397	0%	0%
Bulk carrier	>=200,000	dwt	25	7.39%	5-10%

[14] Design speed is defined as 85% of the MCR (maximum continuous rating).

[15] Speed reduction is the percentage the vessels in a category need to reduce their average speed to comply with the maximum speed limit in the scenario.

Ship type	Size category	Unit	Total # vessels in baseline	Specific speed reduction potential	Speed reduction potential range
Chemical tanker	0-4,999	dwt	1	3.30%	1-5%
Chemical tanker	5,000-9,999	dwt	100	12.17%	>10%
Chemical tanker	10,000-19,999	dwt	370	8.16%	5-10%
Chemical tanker	>= 20,000	dwt	1,229	4.70%	1-5%
Container	0-999	TEU	168	0%	0%
Container	1,000-1,999	TEU	302	0%	0%
Container	2,000-2,999	TEU	222	0%	0%
Container	3,000-4,999	TEU	265	0%	0%
Container	5,000-7,999	TEU	233	0%	0%
Container	8,000-11,999	TEU	266	0%	0%
Container	12,000-14,499	TEU	143	0%	0%
Container	>=14,500	TEU	145	16.12%	>10%
General cargo	0-4,999	dwt	13	31.78%	>10%
General cargo	5,000-9,999	dwt	407	5.04%	5-10%
General cargo	>=10,000	dwt	764	7.14%	5-10%
Liquefied gas tanker	0-4,999	cbm	0	0%	0%
Liquefied gas tanker	5,000-9,999	cbm	3	0%	0%
Liquefied gas tanker	10,000-19,999	cbm	0	6.02%	5-10%
Liquefied gas tanker	20,000-59,999	cbm	0	7.58%	5-10%
Liquefied gas tanker	60,000-79,999	cbm	1	0%	0%
Liquefied gas tanker	80,000-119,999	cbm	0	5.82%	5-10%
Liquefied gas tanker	120,000+	cbm	205	4.17%	1-5%
Oil tanker	0-4,999	dwt	1	0%	0%
Oil tanker	5,000-9,999	dwt	37	0%	0%
Oil tanker	10,000-19,999	dwt	19	8.94%	5-10%
Oil tanker	20,000-59,999	dwt	160	0%	0%
Oil tanker	60,000-79,999	dwt	198	2.59%	1-5%
Oil tanker	80,000-119,999	dwt	508	0%	0%
Oil tanker	120,000-199,999	dwt	366	0%	0%
Oil tanker	>=200,000	dwt	121	4.15%	1-5%

Ship type	Size category	Unit	Total # vessels in baseline	Specific speed reduction potential	Speed reduction potential range
Other liquids tankers	All sizes	dwt	10	16.43%	>10%
Refrigerated cargo	All sizes	dwt	135	19.77%	>10%
Cruise	2,000-9,999	GT	8	2.59%	1-5%
Cruise	10,000-59,999	GT	64	0%	0%
Cruise	60,000-99,999	GT	51	0%	0%
Cruise	>=100,000	GT	32	0%	0%
RoPax	2,000-9,999	GT	57	24.79%	>10%
RoPax	10,000-59,999	GT	312	20.13%	>10%
RoPax	60,000-99,999	GT	6	26.10%	>10%
Ro-Ro cargo	5,000+	dwt	252	0%	0%
Vehicle	All sizes	GT	534	5.87%	5-10%
Gas carrier	All sizes	GT	309	3.84%	1-5%

5.3 Potential benefits of Blue Speeds and the modelling approach applied

5.3.1 Impact on URN

Leaper (2019) reviewed several studies and empirical data on the relationship between vessel speed and broadband source level. Some studies fit a power relationship to empirical data to estimate the relationship between broadband source level and vessel speed. The difference in source level (ΔSL) can be expressed in terms of the ratio of original speed v_0 to final speed v_1 and estimated power exponent z by:

$$\Delta SL = 10z \log\left(\frac{v_1}{v_0}\right) \quad (1)$$

A study that produced a large number of measurements resulted from the voluntary slow down programme initiated by the Vancouver Fraser Port Authority as part of the Enhancing Cetacean Habitat and Observation (ECHO) programme. MacGillivray & Li (2018) obtained estimates of z for several ship types from a total of 2765 source level measurements, including before and after the slow down trial. Another estimate of z is for fishing vessels (Allen, et al., 2012). The estimates of z per ship type are listed in Table 6.

Table 6 - Estimates of z per ship type

Ship type	z	Source
Bulk carrier and general cargo	8.1	(MacGillivray & Li, 2018)
Container ship	5.1	(MacGillivray & Li, 2018)
Vehicle carrier	6.0	(MacGillivray & Li, 2018)
Tanker	7.6	(MacGillivray & Li, 2018)
Cruise/passenger ship	4.5	(MacGillivray & Li, 2018)
Fishing vessels	4.5	(Allen, et al., 2012)

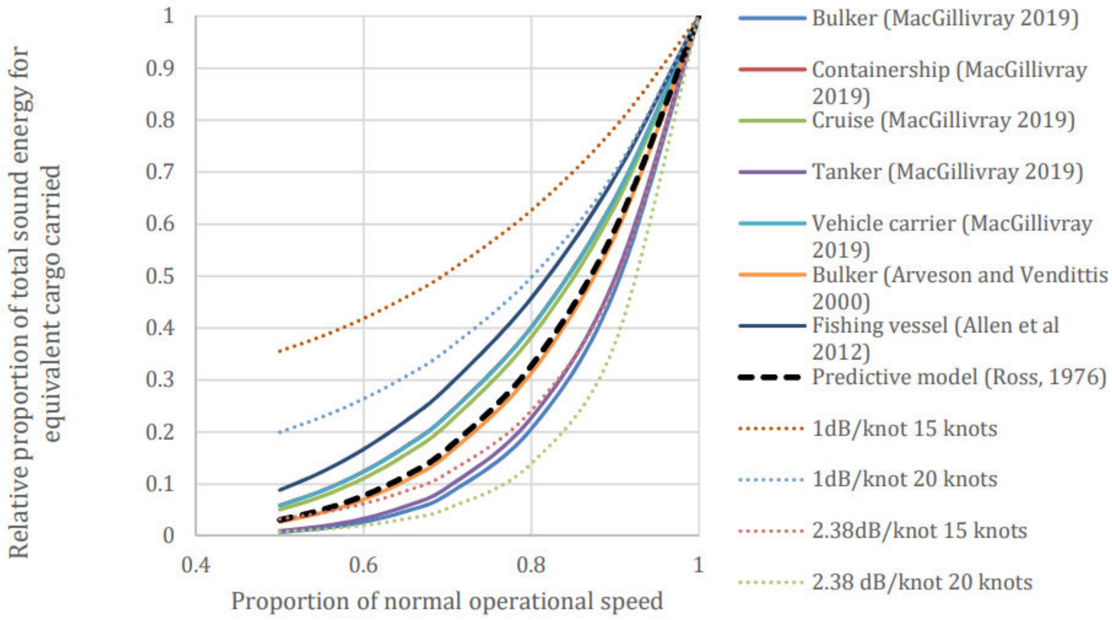
All these relationships of noise with speed only apply to vessels with fixed pitch propellers (FPPs). Substantial cavitation can occur on controllable pitch propellers (CPPs) when operating at slower speeds resulting in higher noise levels. However, vessels with CPPs are only a very small proportion of the global fleet (e.g. tugs and ferries) (Leaper, 2019).

Leaper, et al., (2014) define the acoustic footprint of a vessel as the area of sea for which the source level will be above a given value (which can be defined in terms of energy or pressure). In spherical spreading $(20 \log R)$ propagation loss, the ratio A_1/A_0 of acoustic footprint associated with a change in source level of ΔSL dB is given by:

$$ {A_1}/{A_0} = 10^{\left(\frac{\Delta SL}{10}\right)} \qquad (2) $$

Where A_0 is the original acoustic footprint for SL_0 and A_1 is the footprint associated with SL_1 where $SL_1 = SL_0 + \Delta SL$. The ratio of acoustic footprint is the same as the ratio of total sound energy here. For slower vessels and longer passage times there will need to be more vessels at sea to carry the equivalent amount of cargo. If all vessels travel at a fraction k of their former speed (so $k = v_1/v_0$), the associated acoustic footprints need to be multiplied by $1/k$ for the equivalent cargo carried (Leaper, 2019). For the purposes of this study, the effects of changes in vessel speeds is expressed in terms of the ratio of sound energy for equivalent cargo carried, see Figure 6. For the relationships dependent on the original speed, reference speeds of 15 and 20 knots were taken. For the power relationship in Eq. (1), the ratio of sound energy associated with a proportional reduction in speed will be the same for all speeds and so can be estimated across a fleet regardless of the original speed distribution.

Figure 6 - Relative proportion of total sound energy for equivalent cargo carried from a number of studies. Dotted lines indicate relationships dependent on initial speed. The dashed line indicates $z = 6$ in Eq. (1).



Source: Leaper (2019).

It can be seen from the model (Ross, 1976), that $z = 6$ in Eq. (1) falls in the middle of the more recent empirical studies. We will therefore use this model in our study. This model can be used to calculate the decrease in acoustic footprint for several speed reduction options. A few hypothetical fleet speed reductions and decrease in acoustic footprint are presented as indicative figures in Table 7. A speed reduction of 10% compared to current speeds could already reduce the acoustic footprint by 41%. In the analysis, we apply the actual speed reduction of the fleet in this model to derive the decrease in acoustic footprint in the scenario.

Table 7 - Ratio of acoustic footprint for scenarios of 10-30% speed reductions for a fleet, adjusted for the additional vessels in the fleet, maintaining equivalent annual cargo capacity

Reductions in speed compared to current speeds	10%	20%	30%
Decrease in acoustic footprint using $z = 6$ in Eq. (1)	41%	67%	83%

5.3.2 Impact on energy consumption and fuel expenditures

When ships reduce their speed, not only their URN can be reduced but also their energy consumption. In the following, the energy saving induced by the reduction of the speed are explained in more detail.

When a ship reduces its speed by a certain percentage, the ship’s main engine energy consumption per unit of time (e.g. per hour) is reduced to an even higher extent than this percentage change. As a rule of thumb you can assume that this follows a cubic law.

> To give an example: A 20% speed reduction will reduce a ship’s main engine energy consumption by 48.8% (=1-(1-20%)^3) per unit of time (e.g. per hour).

When a ship reduces its speed, however, this also means that the ship needs more time to cover a certain distance.

> To stick to the example: If the speed is reduced by 20%, the ship needs 25% more time to cover the same distance. The fuel consumption of the main engine for a specific voyage (i.e. given distance) is therefore not reduced by 48.8%, but by 36% (=1-(1-48.8%)*(1+25%)). The resulting rule of thumb: this follows a quadratic law: 36% = $1-(1-20\%)^2$.

It must be considered that while the reduction of speed reduces the energy consumption of the main engines, it does not reduce the energy consumption of the ship's auxiliary engines and boilers. These are relevant for the non-propulsion energy consumption of a ship, such as the energy required for the cooling of cargo, lighting or air conditioning. And given that a ship needs more time to cover the same distance, the ship's auxiliary engine and boiler energy consumption will increase due to a reduction of a ship's speed, thereby leading to an overall lower impact of speed reduction on the energy consumption.

> Assuming that the daily energy consumption of a ship at sea in the initial situation, i.e. without speed reduction, consists to 90% of the consumption of the main engines and to 10% of the consumption of the other energy consumers, then a speed reduction of 20% leads to a reduction of the energy consumption per unit of time by 43.92% (instead of 48.8%) and to a reduction of the energy consumption for the same distance of 29.9% (=1-(1-43.92%)*(1+25%); instead of 36%).

Ships that have a relatively high non-propulsion energy consumption are passenger ships and ships transporting cargo that needs to be cooled.

If one assumes that a ship will provide an unchanged service over the course of a year (i.e. transport of the same volume of goods on the same routes), it may be necessary to use an additional ship if the ship's speed is reduced, as the annual capacity of the ship is limited. The example above has shown that the ship would need 25% more time if it sailed 20% slower, which means that it could only provide an unchanged service if it previously had a corresponding amount of idling time. However, this is not always the case.

Additional ships would then have to take over part of the service. The ship under consideration would carry out fewer voyages per year, but the voyages would each last longer — the ship would also spend less time in ports per year because it would have fewer voyages. Overall, however, given the same transport performance (= same total number of voyages and same amount of cargo carried), the port capacity used (total days in port) and the number of port calls would not change. Only different ships would call at the port, in a situation where additional ships had to be added to the fleet.

The total saving in terms of energy consumed at sea, taking into account the extra ships used, is the same as if the ship still had sufficient free capacity. In the above example, with a speed reduction of 20%, 29.9% of the overall energy consumed at sea would be saved and slightly less taking into account the energy consumption in port, which varies from case to case.

In the analysis, we have considered all the effects as described above to determine the change of the bunker fuel consumption of the fleet, i.e. the effect on the main engine and other energy consumers, accounting for the extra time at sea required per voyage. Since we assume that there is no overcapacity, additional ships are assumed to have to take over some of the voyages. We thereby assume that the additional ships have the same characteristics (same type/size/energy efficiency) as the vessels of the ship category that has to sail slower due to the speed limit. What has not been considered, is a potential energy efficiency loss, which could occur since existing ships have not been optimized to sail at the lower speed.

In order to determine the corresponding change of the fuel expenditures, we have applied three alternative bunker fuel prices in order to account for the uncertainty of the prices. The assumed values are as follows:
1. € 480/tonne fuel.
2. € 630/tonne fuel.
3. € 765/tonne fuel ($ 850/tonne fuel).

The lowest price is in line with the price applied by the European Commission in the impact assessment of the revision of the EU ETS (see 'Modal shift case study'), the medium price reflects the 2030 price for liquid fossil fuels as assumed by the European Commission in the impact assessment of the FuelEU Maritime proposal and the highest price is the current (May 2022) very high bunker fuel price.

5.3.3 Impact on climate and EU ETS expenditures

The maritime shipping sector has a direct and an indirect impact on climate. A direct impact due the sector's GHG emissions and an indirect impact due to ship strikes to whales.

The sector's direct climate impact and the sector's EU ETS expenditures

As discussed in the previous section, the reduction of the speed of a ship leads to a reduction in its energy consumption. If less fossil bunker fuels are consumed by the sector, this also means that the sector emits less GHG emissions — each tonne of bunker fuel consumed is associated with a constant amount of CO_2 emissions, depending on the type of bunker fuel used.

In this study, we have considered ships' CO_2 emissions which are the dominant GHG emissions of the sector. The CO_2 emission factor for the bunker fuel type that is currently dominantly used by the sector (Very low sulphur fuel oil) amounts to 3,114 tonne CO_2/tonne fuel.

In addition, we have also considered the CO_2 emissions of the production of the steel required for building additional ships. To this end we have converted the ships' categories average deadweight tonnage into lightweight tonnage and assumed that the latter corresponds to the weight of steel plates and tubular construction required for building the ships.

For the valuation of the reduction of CO_2 emissions a value of around € 130/tonne CO_2 has been applied (CE Delft, 2018).

Should maritime shipping be integrated into the EU ETS from 2023 onwards, as currently proposed as part of the Fit for 55 policy package, then Blue Speeds could not only lead to a reduction of the sector's GHG emissions and climate impact, but also to a reduction of the sector's EU ETS expenditures. To calculate the sector's potential EU ETS expenditure savings due to Blue Speeds, we applied a carbon price to the fuel savings that corresponds to the EU ETS price from the European Commission's impact assessment of the revision of the EU ETS (COM(2021) 551 final), which is € 45/tonne of CO_2 as average for the period 2021 to 2025. Compared to the current EU ETS price (around € 80/tonne of CO_2 in June 2022), this is a rather conservative assumption, but at this stage the impact of the inclusion of maritime shipping on the EU ETS price is rather uncertain.

The sector's indirect climate impact on climate due to ship strikes to whales

Chami, et al., (2019) have analysed the role that whales play in limiting GHG emissions. They conclude that whales contribute to a reduction of CO_2 in the atmosphere in two ways:
1. Whales serve as carbon reservoirs. All living things can serve as carbon reservoirs, but as relatively large animals, whales can capture a relatively large amount of carbon and once whales die and their carcasses sink to the seafloor the CO_2 is not released to the atmosphere.
2. Whales contribute to the growth of phytoplankton. Like land plants, phytoplankton, also known as microalgae, have chlorophyll to capture sunlight, and they use photosynthesis to turn it into chemical energy. They consume carbon dioxide, and release oxygen. Phytoplankton are responsible for most of the transfer of carbon dioxide from the atmosphere to the ocean (Lindsay & Scott, 2010). With their nutrient-rich excrements, whales stimulate the growth of phytoplankton and this fertilizing activity seems to significantly add to phytoplankton growth in areas whales frequent.

A lethal ship strike of a whale would therefore limit the whale's CO_2 emission reduction potential.

Chami, et al., (2019) have estimated the value of an average great whale at more than $ 2 million. The indicated value not only considers the carbon sequestered by a whale over its lifetime (which is stated to be around 40 years), but also considers a whale's other economic contributions, such as fishery enhancement and ecotourism. They consider this estimate a conservative estimate.

For the social cost-benefit analysis, we have estimated the reduction in the lethal whale collision hazard in European seas due to Blue Speeds, applying the weighted average baseline speed of the EU MRV fleet (11.6 knots) and the resulting average speed reduction (-4.7%). The underlying methodology will be explained in more detail in the following subsection. Subsequently, we applied the resulting estimated decrease in lethal whale collision hazard (-23%) to the average yearly number of ship strikes to whales in European waters as discussed by Winkler, et al., (2020). By multiplying the number of whale strikes per year and the estimated decrease in lethal collision hazard, we obtain the potential of reduction in the number of lethal whale strikes per year. The economic value of a whale, as determined by Chami, et al., (2019), is used to quantify the annual benefits of the reduced whale strike hazard. To this end, the lifetime value of a whale, as determined by Chami, et al., (2019) is evenly spread over the expected lifetime of a whale (40 years) and it is assumed that a ship strike has been prevented if a whale reaches half of its lifetime.

Estimation of decrease in lethal whale collision hazard

Collisions between cetaceans and ships occur worldwide where shipping overlaps with cetacean habitats. Collisions can lead to injury and/or death of cetaceans and causes damage to the ships. In response to this threat, the IMO issued guidance on minimizing the risk of ship strikes to cetaceans (IMO, 2009). The International Whaling Commission (IWC) has concluded that the only proven, effective mitigation measures to reduce ship strikes to whales are to avoid areas with known concentrations of whales, or reduce speed while transiting those areas (IWC, 2016).To give an example: The voluntary speed limit as initiated in the Hauraki Gulf in New Zealand is an example of a speed limit that has been shown to have significantly reduced the probability of lethal ship strikes to whales (see for example Ebdon, et al., (2020)). Since most whale populations are widely dispersed and distribution patterns are not predictable enough to allow routing measures (Leaper, 2019), these situations would benefit from more general risk reduction measures. Here we will analyse the effects of Blue Speeds on lethal ship strikes to whales in European waters, without Blue Speeds being restricted to specific areas.

The relationship between vessel speed and lethal ship strikes to whales has been reviewed by Leaper (2019). The probability of a fatal ship strike can be expressed as the probability that a strike will occur multiplied by the probability that it will ultimately be fatal given that it has occurred. The relationship between these probabilities and vessel speed has been studied in most detail for North Atlantic right whales. Van der Laan & Taggert (2007) estimates the probability of lethal injury based on the vessel speed at the time of impact (M_v), which was later updated by Conn & Silber (2013)with additional data. In that case M_v for speed v (in knots) was expressed as:

$$\boldsymbol{M_v} = \frac{\exp(\beta_0+\beta_1 v)}{\exp(\beta_0+\beta_1 v)+1} \quad (3)$$

Where β_0 was estimated as -1.905 (with $\mathrm{SE} = 0.821$) and β_1 as 0.217 ($\mathrm{SE} = 0.058$). Conn & Silber (2013) also estimated the relative instantaneous strike rate based on speed. They expressed this in the form:

$$\log(\boldsymbol{\lambda}) = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_1 v} \quad (4)$$

Where λ is the instantaneous rate at which whales are struck. It was not possible to estimate α_0, therefore we only have a relative estimate of strike rate with speed with $\alpha_1 = 0.49$ ($SE = 0.09$). This formulation generates an exponential increase in strike rate with speeds which becomes unrealistic at high speeds. In the analysis of Leaper (2019) 99% of observed ship speeds were 20.5 knots or below, therefore we assume λ to be constant for speeds higher than 20 knots. Conn & Silber (2013) then derived an expression for an index of the total mortality hazard based on the sum of the independent relative hazards associated with each transit through an area. The relative hazard for each individual transit is expressed as $\lambda_v M_v D_v$ where $\mathrm{D_v}$ is the duration of the transit for vessel speed v. Thus D_v is proportional to $1/\mathrm{v}$.

$$\mathbf{H_v} = \frac{\lambda_v M_v}{v} \quad (5)$$

To correct for the increase in number of vessels, we multiplied H_v with the number of vessels in the new situation n_v and divided this by H_0 multiplied by the number of vessels in the old situation n_0, to get to the decrease in relative hazard:

$$ratio\ of\ lethal\ whale\ collision\ hazard = \frac{H_V n_1}{H_0 n_0} \qquad (6)$$

Using this model we calculated the decrease in lethal whale collision hazards for several speed reduction options, see Table 8. A 10% reduction in speed could already decrease the hazard for lethal whale collisions by 42%. Winkler, et al., (2020) made an assessment of collisions between vessels and cetaceans using reported collision data from the IWC Ship Strike Database. Using their data for European waters and more recent numbers on collisions, we calculated that a 10% reduction in speed could reduce the absolute number of lethal ship strikes by (at least) 14 per 10 years in European seas based on the 2018 composition of the EU MRV fleet. Note, however, that the number of ship strikes is heavily underreported, and therefore the actual number of lethal ship strikes prevented is expected to be much higher.

Table 8 - Ratio of lethal whale collision hazard for scenarios of 10-30% speed reductions of the EU MRV fleet, adjusted for the same cargo carried (additional vessels). V_0 = 11.6 knots (weighted average of the 2018 EU MRV fleet)

Reductions in speed compared to current speeds	10%	20%	30%
Decrease in lethal whale collision hazard	42%	67%	81%

The dominant factor affecting the variance of estimates of H_v is uncertainty in λ. At 15 knots, the difference in λ between $\alpha_1 \pm$ one standard error is a factor of over 200. Thus, any estimates based on H_v need to be treated with caution.

5.3.4 Impact on air pollution and related health/environmental effects

As discussed above, the reduction of the speed of a ship can lead to a reduction of the sector's GHG emissions due to reduced energy/fuel consumption. Air pollutants emitted by the sector not only depend on energy consumption, but also on other factors. In this study, we have considered SO_x and NO_x emissions of the sector as follows:

- The SO_x emissions also depend on the sulphur content of the fuel consumed. MARPOL Annex VI, Regulation 14, limits the sulphur content of the fuel used to 0.10% m/m if used in Emission Control Areas (ECAs) and to 0.50% m/m is used outside ECAs. There are currently four SECAs designated worldwide: the Baltic Sea area, the North Sea area, the North American area and the United States Caribbean Sea area. From the EU MRV fuel consumption data we have roughly estimated the share of the fuel consumed with a low and a high fuel sulphur content. For the low sulphur fuel we applied an SO_x emission factor of 1.17 kg per tonne of fuel and for the high fuel 8.78 kg per tonne of fuel.
- The NO_x emissions also depend on the engine that burns the fuel. MARPOL Annex VI, Regulation 13, sets limits to the NO_x emissions of diesel engines for newbuild ships. The strictest limits hold for ships sailing in ECAs. For the purpose of this study we used the average NO_x emission factor as stated in the 4th IMO GHG study (Faber, et al., 2020), which is 75.9 kg NO_x per tonne HFO.

For an assessment of the impacts of the reduced air pollution from shipping, the ‘Handbook on the external costs of transport’ (CE Delft, et al., 2019) provides average damage costs in €/kg emission, specific for maritime emissions, considering health effects, crop loss, biodiversity loss, material damage as given in Table 9.

Table 9 – Average damage costs for maritime emissions

€$_{2016}$/kg	**NO_x**	**SO_2**
Atlantic	3.8	3.5
Baltic	7.9	6.9
Black Sea	7.8	11.1
Mediterranean	3	9.2
North Sea	10.7	10.5

Source: CE Delft, et al., (2019).

5.4 Potential costs of Blue Speeds and the modelling approach applied

5.4.1 Engine modification costs for existing ships

If a mandatory speed limit was implemented, technical adjustments to the engine or other elements of the ships might be required in order to lower the power of the engine or to re-optimise the engine and the elements accordingly. Therefore (engine) modification costs can accrue.

In the analysis, we have considered engine modification costs only. Other modification costs can vary widely between ship types and sizes and it is uncertain whether a ship owner will re-optimise other elements of the ship too. We based the engine modification costs on costs as stated in interviews and the literature (Faber, et al., 2012) at $ 200,000 per vessel spread them over the remaining life time of the vessels, applying the following simplifying approach: We assume that ships’ life time is 30 years and that the number of ships is evenly distributed over the ages, then the average remaining life time of the ships amounts to 15.5 years.

5.4.2 Adjustment of supply chains

When ships that are carrying cargo sail at a lower speed than usual, an adjustment of supply chains may be required to accommodate the slower speed of the vessels.

With the introduction of a speed limit, ships affected by the speed limit would arrive later than usual at their destination. If the ship carries the same volume of cargo as usual and there is no extra inventory available at the destination, this could lead to an interruption of production/sales at the destination. To prevent this, the supply chain could be adjusted in different ways:
- Larger ships could be used. This requires larger quantities of the cargo to be shipped to become available and could result in a one-off shortage for the consignee, with the first batch arriving later than usual.
- Alternatively, different ships of the same size could be used that sail alternately. This again might result in a one-off shortage for the consignee, but after that, the same amount of cargo could be shipped at the usual dates and could also arrive at the usual dates, only the transit time per shipment differs.

For a supply chain that does not rely on just-in-time production and works with (relatively high) inventories, it is also possible that there is a degree of flexibility available so that, apart from the transportation of the cargo, there is no need to adjust the supply chain and that only the on-land inventories would shrink.

It is also possible that, by adapting port logistics, the current waiting time of the ships could be used to allow the ships to sail more slowly instead. In this case, the extra transit time of the ships could be minimized and, at the same time, no/only a minor adjustment of the supply chain might be necessary.

In practice, the need for an adjustment of a supply chain and the actual adjustment costs can thus be expected to differ highly from case to case and are difficult to determine.
For the purpose of this study, we have focussed on the costs associated with additional ship capacity and additional financing costs for the cargo which will be explained in more detail in the following.

5.4.3 Costs associated with additional ship capacity

When cargo carrying ships are required to slow down, voyages take longer and extra ship capacity is required if the same transport work is to be provided. This leads to additional operational and maintenance costs and, if additional ships have to be added to the fleet, also to additional capital expenditures.

To give an example: if a container ship sails from the Port of Shanghai to the Port of Rotterdam and sails on average at 16.5 knots (which is the average 2018 baseline speed as determined for the largest container ship category), then it takes around 26.5 days to cover the distance of around 10,500 nautical miles. If the ship sailed on average at around 13 knots instead (which is around 16% slower and which is the expected average speed if the speed was limited to 75% of the design speed) then the distance could be covered in around 31.5 days instead. The transit time would by 19% which in this case corresponds to 5 days.

In the analysis we have assumed that the fleet under consideration has almost no spare capacity and that the additional capacity required is provided by additional new ships that will be added to the fleet. Only in case the reduction of the speed requires a non-substantial additional amount of days at sea for a ship category per year, we assumed that the use of the existing ship capacity can be optimized and that no extra vessels need to be built.

An assessment of the potential overcapacity in the different ship segments is currently rather difficult. Markets are picking up after the COVID-19 pandemic crisis and due to ongoing staff shortages, logistical disruptions, including port congestion, currently result in a shortage of available capacity, especially in the container segment. On top of this, the Russia-Ukraine conflict has led to structural changes especially in the tanker and dry bulker markets. Port congestion and logistical disruption can be expected to eventually unwind, but this cannot be expected to lead to an overcapacity in all segments. Also considering the growth of the demand for and the supply of maritime transport, in the short run (2022/2023), potential overcapacity is more likely to emerge in the tanker/LPG carrier markets than in the other segments, if at all (based on Clarksons Research (2022)).

The new ships added to the fleet are assumed to be dedicated ships that operate, as far as required, within the scope of the EU MRV and are ships of the same type/size category as the ships that are required to reduce their speed. The capital expenditures for these additional new ships are entirely allocated to the costs associated with the Blue Speeds limit, whereas the daily operational costs for these ships are only accounted for in the extra operating days required due to the speed limit. In the year analysed, the entire capital costs of the new ships was not considered, but the investment costs for the acquisition of new vessels is 'spread' over the lifetime of the vessels. The corresponding annuities (annual even payments for the loan), are determined based on the assumption that capital costs are paid off over 30 years at an interest rate of 7.5% as applied by major firms in the maritime transport sector.

The price for the newbuild ships is based on price data as available at Clarksons Shipping Intelligence Network and the ships daily operational and maintenance costs stem from Drewry Maritime Research (2018), including costs for manning, insurance, stores, spares, lubricating oils, repair & maintenance, dry docking, management and administration. Note that insurance costs per day may go down due to slow steaming, but we were not able to quantify this potential effect.

5.4.4 Additional financing costs for cargo

We assume that the cargo that is transported by the ships is financed externally, which means that interest rates accrue, depending on the transit time over sea. Due to slow steaming, transit time over sea will increase, leading to additional financing costs.

In order to estimate these additional financing costs, we have estimated the value of the cargo transported by the ships to approximate the capital required in the baseline for purchasing the commodities before shipment.[16] We therefore used the 2018 value of extra-EU trade by sea, differentiated by main product categories as provided by Eurostat (see Table 10) and allocated the value over the different ship types, selecting the most likely ship type per product category. We thereby neglected the value of the intra-EU seaborne trade in order to correct for the fact that we have not considered the fleet of ships under 5,000 GT and the expectation that the speed reduction potential on intra-EU voyages (and thus mainly coastal shipping) is likely to be relatively small. For the calculation of the additional financing costs, we assume an interest rate of 5%.

Table 10 – 2018 value of extra-EU trade by sea (€ billion)

Cargo item	Extra-EU import by sea	Extra-EU export by sea
Agricultural products and live animals	35.5	21.4
Foodstuffs and animal fodder	79.3	83.9
Solid mineral fuels	15.5	855.3
Petroleum products	283.8	84.6
Ores and metal waste	26.9	15.1
Metal products	59.1	39.4
Crude and manufactured minerals, building materials	6.7	10.8
Fertilisers	4.0	2.2
Chemicals	88.9	136.8
Machinery, transport equipment, manufactured articles and miscellaneous articles	488.9	520.7
Total	**1,089**	**916**

Source: Eurostat (Extra-EU trade since 2000 by mode of transport (NSTR); DS-022469).

[16] Since the values given in Eurostat reflect the value when the goods/commodities cross the EU border, the value of the exports as given in Eurostat better reflects the capital required for purchasing the commodities before shipment than the value of the imports.

5.5 Outcome of social cost-benefit analysis

In the social cost-benefit analysis, we calculated the aforementioned physical effects and their monetary values on Blue Speeds (see end of Section 4.5.2 for a summary of the design of the measure). The outcome of the social cost-benefit analysis is presented in the following.

Due to Blue Speeds, the weighted average speed of the entire EU MRV fleet (including additional vessels) is reduced by 4.7%. About a third of the baseline fleet is currently sailing at a speed that is 70% or less of their design speed. Table 11 gives an overview of the estimated physical effects of Blue Speeds on the EU MRV fleet.

Table 11 – Overview of estimated physical effects of Blue Speeds

Item	Unit	Baseline	Change due to speed limit	Value in speed reduction scenario
Weighted sound level	Underwater radiated noise (sound energy)	-	-25.1%	-
Weighted average speed (entire fleet)[a]	Knots	11.62	-0.54 (-4.7%)	11.08
Total fuel consumption of shipping	Megaton/year	43.5	-3.5 (-8.1%)	40.0
Total CO_2 emissions from shipping	Megaton/year	136.0	-11.0 (-8.1%)	125.0
Number of vessels EU MRV fleet	# of vessels	11,676	+197	11,873
CO_2 emissions ship building (by steel production)[b]	Megaton	0	+12.8	12.8
Total SO_2 emissions	**tonne/year**	**343,000**	**-27,000 (-7.9%)**	**316,000**
Total NO_x emissions	**tonne/year**	**3,304,000**	**-267,000 (-8.1%)**	**3,037,000**

a The indicated reduced speed includes the additional vessels added to the fleet in the speed reduction scenario.

b One-off emissions in year of build; monetary value spread over life time of ship assumed to be 30 years.

The noise change, as a result of the speed reduction of the ship categories adjusting their speed (as listed in Table 5), is about 25% in sound energy released at the fleet level, including the increase of the fleet by 197 vessels. This is the noise reduction in terms of radiated noise in the proximity of vessels. Note in this context that we have assumed in the analysis that the fleet under consideration has no spare capacity and that the additional capacity required due to the speed reduction is provided by additional new ships that will be added to the fleet. These new ships are assumed to be ships of the same type/size category as the ships that are required to reduce their speed. Should larger ships be used for the adjustment of the logistical chain in practice, then the induced noise reduction might be different. Larger ships in general produce more noise.

The reduction of fuel consumption of the existing fleet, adjusted for the additional time at sea is about 3.4 million tonne fuel oil. To obtain the total change in fuel consumption, the increase of fuel use of additional vessels is added, which is approximately 1.2 million tonnes fuel oil. The total change in fuel use in the speed reduction scenario of the fleet including the additional vessels is a reduction of 2 million tonnes of bunker fuel compared to the baseline fuel use of the fleet.

The annual reduction in CO_2 emissions from fuel combustion is 8.3 Mt. The CO_2 emissions related to the steel production for the additional vessels amount to 12.8 Mt at the time of production. Spread over the lifetime of the ship, which is 30 years on average, the corresponding annuitized shipbuilding CO_2 emissions are around 0.43 Mt.

The change of air pollution emissions (SO_2, NO_x) has also been calculated. Due to a total reduction of fuel consumption, air pollutants are also lower in the speed reduction scenario. The SO_x emissions are estimated to be reduced by about 26,000 tonnes, and NO_x emissions by 258,000 tonnes.

The effects in monetary terms have been derived by applying market prices and shadow prices, the latter as provided by the European handbook on the external costs of transport. As stated in the sections above, a range of fuel prices has been considered. This resulted in a significant range of estimated fuel expenditure savings. See Table 12 for the results of the cost-benefit analysis. All figures represent changes in yearly costs compared to the baseline scenario. Thus, *negative costs* indicate a *benefit* in the speed reduction scenario. The costs are based on the baseline year 2018.

Table 12 - Overview of annual costs and benefits due to Blue Speeds

Item	**€ million per year**		
Fuel costs (low-med-high)	€ -1,692	€ -2,211	€ -2,701
ETS cost	€ -344		
Environmental costs marine ecology (less ship strikes to whales)	€ -0.1		
Environmental costs CO_2 emissions fuel combustion	€ -1,463		
Environmental costs CO_2 emissions ship building	€ 56		
Environmental costs SO_x emissions	€ -174		
Environmental costs NO_x emissions	€ -1,365		
Additional vessel acquisition costs + additional O&M costs	€ 926		
Engine modification costs (existing fleet)	€ 160		
Additional financing costs	€ 402		
Other costs for logistic chain adjustments + administrative costs	Pro memoria (P.M.)		
Total cost change	**€ -3,494 +/- P.M.**	**€ -4,013 +/- P.M.**	**€ -4,503 +/- P.M.**

It can be concluded that, depending on the fuel price and the EU ETS allowance price, the sectoral benefits of Blue Speeds (fuel and EU ETS expenditure savings) can outweigh the sectoral costs of Blue Speeds.

Also considering the environmental benefits of Blue Speeds, the overall benefits of Blue Speeds can outweigh their costs for a wide range of fuel prices. The total benefits of Blue Speeds have been estimated to amount to around € 3.4 billion to € 4.5 billion per year, depending on the price of bunker fuel. This does not, however, include potential benefits for the fishing industry, cost of logistic chain adjustments other than additional financing costs for the cargo (due to longer transit times) as well as administrative costs, both for the shipping industry as well as the EU/national administrations.

If there is overcapacity available in the shipping market, which allows the use of the capacity of existing ships instead of new ships to accommodate Blue Speeds, then the presented costs associated with Blue Speeds can be reduced further.

A complementary measure, to facilitate the optimisation of port logistics with the aim to accommodate Blue Speeds and reduce waiting time can significantly reduce the need to adjust logistic chains and thus also the costs associated with Blue Speeds.

Should the EEXI and/or the EU ETS incentivize ships to reduce their speed independent of Blue Speeds, then the effects of Blue Speeds can be expected to be smaller. Compared to the EU ETS, however, Blue Speeds would ensure that ships reduce their speed on a structural basis.

6 Conclusions

Underwater radiated noise (URN) from shipping can be harmful to the marine environment.

The study investigates a limitation of the speed of ships to implement ‘Blue Speeds’ - speed levels that protect the marine environment from negative impacts of URN and that are associated with co-benefits for both marine life and humans by reducing the hazard of ship strikes to whales, GHG emissions and air pollution.

There are various policy options to ensure that ships engaged in EU-related maritime transport sail at Blue Speeds. This report analyses these options and proposes preferred options, considering environmental effectiveness, political and legal feasibility

More specifically, a social cost-benefit analysis is carried out for a maximum speed limit for all ships sailing to and from EEA ports, with the limit set at 75% of the ships’ design speed. The social costs and benefits are thereby quantified as far as possible, using 2018 EU MRV data and following an anthropogenic approach. Co-benefits in terms of potentially less ship strikes to whales and lower GHG and air pollution emissions of ships are also considered in the analysis.

We find that, as a result of the implementation of Blue Speeds, the sound energy released by the ships of the EU MRV fleet can be expected to decrease by around 25%. An increase in the fleet by 1.7% (197 vessels) has thereby been accounted for in this estimate. A potential adjustment of logistic chains by using larger ships, which has not been considered, could lead to a lower noise reduction since larger ships in general produce more intense sound levels at lower frequencies.

Blue Speeds will reduce the probability of ship strikes to whales by 23% and can thereby have an indirect positive impact on humans, since whales contribute to a reduction of CO_2 in the atmosphere.

The analysis also shows that, at the fleet level, Blue Speeds lead to a net reduction of fuel consumption, CO_2 emissions and air pollution from shipping of around 8% each. Extra CO_2 emissions will be emitted due to the building of additional ships that are required to ensure that the fleet’s transport work is kept at the same level, but these are significantly lower than the CO_2 emission reductions achieved in the shipping sector on an annual basis.

Blue Speeds are also associated with costs, such as the costs for the acquisition of newbuilds, additional costs for the operation and maintenance of ships which accrue due to the increase in transit times, engine modification costs and additional financing costs for the cargo, also due to longer transit times.

Depending on the fuel price and the EU ETS allowance price, the sectoral benefits of Blue Speeds (fuel and EU ETS expenditure savings) can outweigh the sectoral costs of Blue Speeds.

Altogether, weighing the monetized benefits against the costs, including the external effects, Blue Speeds lead to a social benefit of between € 3.4 billion to € 4.5 billion per year, depending on the bunker fuel price. This however does not include potential benefits for the fishing industry, costs for logistic chain adjustments other than additional financing costs for the cargo (due to longer transit times) as well as administrative costs, both for the shipping industry as well as the EU/national administrations.

If there is overcapacity in the shipping market, which allows existing ships to be used to implement Blue Speeds instead of new ships, then the presented costs associated with Blue Speeds can be further reduced.

A complementary measure to facilitate the optimisation of port logistics with the aim of accommodating Blue Speeds and reduce waiting times, can significantly reduce the need to adjust logistic chains and thus also the costs associated with Blue Speeds.

Should the Energy Efficiency Existing Ship Index (EEXI), the FuelEU Maritime Regulation and/or the EU ETS incentivise ships to reduce their speed independent of Blue Speeds, then some of the benefits of Blue Speeds would already occur. Compared to the FuelEU Maritime Regulation and EU ETS, however, Blue Speeds would ensure that ships permanently reduce their speed.

7 References

ABS, 2021. *Practical considerations for underwater noise control.* [Online] Available at: https://ww2.eagle.org/content/dam/eagle/publications/whitepapers/underwater-noise-control-whitepaper-21011.pdf [Accessed 2022].

Aguilar de Soto, N., Johnson, M., Madsen, P. T. & Tyack, P., 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (Ziphius cavirostris)?. *Marine Mammal Science,* 3(22), pp. 690-699.

Allen, J. K., Peterson, M. L., Sharrard, G. V. & Wright, D. L., 2012. Radiated noise from commercial ships in the Gulf of Maine: implications for whale/vessel collisions. *The Journal of the Acoustical Society of America,* Volume 132, pp. 229-235.

André, M. et al., 2017. Sperm whale long-range echolocation sounds revealed by ANTARES, a deep-sea neutrino telescope. *Nature Scientific Reports,* Issue 7, p. 45517.

AQUO & SONIC consortia, 2015. *Guidelines for regulation on UW noise from commercial shipping, Suppression of UW noise reduced by caviatation: SONIC deliverable 5.4 (project AQUO-SONIC),* s.l.: s.n.

Arranz, P. et al., 2016. Discrimination of fast click-series produced by tagged Risso's dolphins (Grampus griseus) for echolocation or communication. *Journal of Experimental Biology,* 219(18), pp. 2898-2907.

Au, W. & Green, M., 2000. Acoustic interaction of humpback whales and whale-watching boats. *Marine Environmental Research,* 49(5), pp. 469-481.

Au, W. W. L., 2018. *Echolocation,* s.l.: Encyclopedia of Marine Mammals (pp. 289–299). Elsevier.

Bagočius, D., 2015. Piling underwater noise impact on migrating salmon fish during Lithuanian LNG terminal construction (Curonian Lagoon, Eastern Baltic Sea Coast). *Marine Pollution Bulletin,* 92(1-2), pp. 45-51.

BIMCO, 2011. *Slow Steaming Clause for Time Charter Parties 2011.* [Online] Available at: https://www.bimco.org/Contracts-and-clauses/BIMCO-Clauses/Current/Slow_Steaming_Clause_for_Time_Charter_2011 [Accessed May 2022].

BIMCO, 2012. *Slow Steaming Clause for Voyage Charter Parties 2012.* [Online] Available at: https://www.bimco.org/Contracts-and-clauses/BIMCO-Clauses/Current/Slow_Steaming_Clause_for_Voyage_CP_2012 [Accessed May 2022].

BIMCO, 2013. *Virtual Arrival Clause for Voyage Charter Parties 2013.* [Online] Available at: https://www.bimco.org/contracts-and-clauses/bimco-clauses/current/virtual_arrival_clause_for_voyage_charter_parties_2013 [Accessed May 2022].

Blair, B. et al., 2016. Evidence for ship noise impacts on humpback whale foraging behaviour. *The Royal Society Biology Letters,* 8(12).

Blomqvist, C. & Amundin, M., 2004. High-Frequency Burst-Pulse Sounds in Agonistic/Aggressive Interactions in Bottlenose Dolphins, Tursiops truncatus. In: *Echolocation in Bats and Dolphins.* Chicago: The University of Chicago Press, pp. 425-431.

Blue Visby, ongoing. *Blue Visby Solution™.* [Online] Available at: https://bluevisby.com/ [Accessed May 2022].

Buckstaff, K. C., 2004. Effects of watercraft noise on the acoustic behavior of bottlenose dolphins, Tursiops truncatus, in Sarasota Bay, Florida. *Marine Mammal Science,* 20(4), pp. 709-725.
Bureau Veritas, DCNS & Quiet-Oceans, 2015. *WP 5: Guidelines to reduce ship noise footprint, D5.8 Synthesis of recommendations, "Underwater Noise Footprint of Shipping: The "Practical Guide",* s.l.: AQUO Project Consortium 2015.
Caldwell, M. C., Caldwell, D. & Miller, J., 1973. Statistical evidence for individual signature whistles in the spotted dolphin. *Cetology,* Volume 16, pp. 1-21.
Canal de Panama, 2020. *The Panama Canal Resumes Seasonal Measures to Protect Marine Life and Reduce Emissions.* [Online]
Available at: https://pancanal.com/en/the-panama-canal-resumes-seasonal-measures-to-protect-marine-life-and-reduce-emissions/
[Accessed May 2022].
Castellote, M., Clark, C. W. & Lammers, M., 2012. Acoustic and behavioural changes by fin whales (Balaenoptera physalus) in response to shipping and airgun noise. *Biological Conservation,* 1(147), pp. 115-122.
Castellote, M. et al., 2018. Anthropogenic noise and the endangered Cook Inlet beluga whale, Delphinapterus leucas: Acoustic considerations for management. *Marine Fisheries Review,* 3(80), pp. 63-88.
CE Delft, 2018. *Environmental Prices Handbook 2017,* Delft: CE Delft.
CE Delft, INFRAS, TRT & Ricardo, 2019. *Handbook on the external costs of transport, Version 2019 - 1.1,* Delft: CE Delft.
Chami, R., Cosimano, T., Fullenkamp, C. & Oztosun, S., 2019. Nature's Solution to climate change. *Finance & Development*, December, pp. 34-38.
Clarksons Research, 2022. *Shipping Review & Outlook March 2022,* London: Clarksons Research Services Limited.
Clausen, K. T. et al., 2011. Click communication in harbour porpoises, Phocoena phocoena. *Bioacoustics,* 20(1), pp. 1-28.
Conn, P. B. & Silber, G. K., 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. *Ecosphere,* 4(4), pp. 1-16.
de Jong, K. et al., 2020. Predicting the effects of anthropogenic noise on fish reproduction. *Reviews in Fish Biology and Fisheries,* Volume 30, pp. 245-268.
DNV GL, ongoing. *GLOMEEP, Information Portal, Engine de-rating.* [Online]
Available at: https://glomeep.imo.org/technology/engine-de-rating/
[Accessed May 2022].
DNV, 2021. *First DNV SILENT-E class notation awarded to a merchant vessel.* [Online]
Available at: https://www.dnv.com/expert-story/maritime-impact/First-DNV-SILENT-E-class-notation-awarded-to-a-merchant-vessel.html
[Accessed May 2022].
DNV, ongoing. *EEXI – Energy Efficiency Existing Ship Index, FAQs, EEXI general questions.* [Online]
Available at: https://www.dnv.com/maritime/insights/topics/eexi/answers-to-frequent-questions.html
[Accessed May 2022].
Drewry Maritime Research, 2018. *Ship Operating Costs, Annual Review and Forecast, Annual Report 2018/2019,* London: Drewry.
Dunn, C., Theriault, J., Hickmott, L. & Claridge, D., 2021. Slower Ship Speed in the Bahamas Due to COVID-19 Produces a Dramatic Reduction in Ocean Sound Levels. *Frontiers in Marine Science,* 8(Article 673565).
Ebdon, P., Riekkola, L. & Constantine, R., 2020. Testing the efficacy of ship strike mitigation for whales in the Hauraki Gulf, New Zealand. *Ocean & Coastal Management,* 148(105034).

EC, 2020. *REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the implementation of the Marine Strategy Framework Directive (Directive,* Brussels: European Commission (EC).
EC, 2021. *Environment.* [Online]
Available at: https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/review_of_the_directive.htm
[Accessed May 2022].
EC, 2021. *News - Commission presents Renewable Energy Directive revision.* [Online]
Available at: https://ec.europa.eu/info/news/commission-presents-renewable-energy-directive-revision-2021-jul-14_en
[Accessed May 2022].
EC, ongoing a. *Our Oceans, Seas and Coasts - MSFD Descriptor 11: Energy incl. Underwater Noise.* [Online]
Available at: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-11/index_en.htm
[Accessed May 2022].
EC, ongoing b. *Reducing emissions from the shipping sector.* [Online]
Available at: https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-shipping-sector_en
[Accessed May 2022].
EMB, 2021. *Addressing underwater noise in Europe, Current state of knowledge and future priorities,* Ostend: European Marine Board (EMB) IVZW.
EMSA, 2021. *SOUNDS: Status of underwater noise from shipping,* Lisbon: European Maritime Safety Agency (EMSA).
EMSA, 2022. *THETIS-MRV, CO2 Emission Report.* [Online]
Available at: https://mrv.emsa.europa.eu/#public/emission-report
[Accessed May 2022].
Erbe, C. et al., 2019. The Effects of Ship Noise on Marine Mammal - A Review. *Frontiers in Marine Science,* 6(October 2019).
Faber, J. et al., 2020. *Fourth IMO Greenhouse Gas Study,* London: IMO.
Faber, et al., 2012. *Regulated Slow Steaming in Maritime Transport,* Delft: CE Delft.
Fearey, J., Elwen, S. H., James, B. S. & Gridley, T., 2019. *Identification of potential signature whistles from free ranging common dolphins (Delphinus delphis) in South Africa,* s.l.: Animal Cognition, 22(5).
Filiciotto, F. et al., 2014. Behavioural and biochemical stress responses of Palinurus elephas after exposure to boat noise pollution in tank. *Marine Pollution Bulletin,* 84(1-2), pp. 104-114.
Forsman, N., 2018. *ICEEDI, Power requirements according to FSIC rules and EEDI compliance, SSPA Report No.: RE40168034-01-00-A,* Göteborg: SSPA Sweden AB.
Gabriele, C. M. et al., 2018. Underwater Acoustic Ecology Metrics in an Alaska Marine Protected Area Reveal Marine Mammal Communication Masking and Management Alternatives. *Frontiers in Marine Science,* 5(Article 270).
Guerra, M., Dawson, S. M., Brough, T. E. & Rayment, W. J., 2014. Effects of boats on the surface and acoustic behaviour of an endangered population of bottlenose dolphins. *Endangered Species Research,* 3(24), pp. 221-236.
Guzman, H., Hinojosa, N. & Kaiser, S., 2020. Ship's compliance with a traffic separation scheme and speed limit in the Gulf of Panama and implications for the risk to humpback whales. *Marine Policy,* 120(104113).
Harris, R., Miller, G. & Richardson, W., 2001. Seal Responses to Airgun Sounds During Summer Seismic Surveys in the Alaskan Beaufort Sea. *Marine Mammal Science,* 17(4), pp. 795-812.

Heiler, J., Elwen, S., Kriesell, H. & Gridley, T., 2016. Changes in bottlenose dolphin whistle parameters related to vessel presence, surface behaviour and group composition. *Animal Behaviour,* Issue 117, pp. 167-177.
Hildebrand, J., 2004. *Sources of Anthropogenic Sound in the Marine Environment.* International Policy Workshop on Sound and Marine Mammals, London, 28-30 , s.n.
Holt, M. M. et al., 2009. Speaking up: Killer whales (Orcinus orca) increase their call amplitude in response to vessel noise. *The Journal of the Acoustical Society of America,* 125(1), pp. EL27-EL32.
ICCT, 2020. *Potential CO2 reductions under the Energy Efficiency Existing Ship Index, Working Paper 2020-27,* Washington: ICCT.
IMO, 2009. *Guidance Document for Minimizing the Risk of Ship Strikes with Cetaceans,* London: IMO.
IMO, 2021. *Further shipping GHG emission reduction measures adopted.* [Online] Available at: https://www.imo.org/en/MediaCentre/PressBriefings/pages/MEPC76.aspx [Accessed May 2022].
IMO, 2022. *Sub-Committee on Ship Design and Construction (SDC 8), 17-21 January 2021.* [Online] Available at: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/SDC-8.aspx [Accessed May 2022].
IMO-GloMEEP & GIA, 2018. *White Paper on the "Validation of the Performance of Energy Efficiency Technologies for ships",* s.l.: Global Industry Alliance (GIA).
IMO, ongoing a. *Particularly Sensitive Sea Areas.* [Online] Available at: https://www.imo.org/en/OurWork/Environment/Pages/PSSAs.aspx [Accessed May 2022].
IMO, ongoing b. *Ship noise.* [Online] Available at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Noise.aspx [Accessed May 2022].
INTLREG, 2019. *NIEUWS - IMO-navigatieregels in de Straat van Malakka en Singapore.* [Online] Available at: https://intlreg.org/2019/12/07/imo-navigation-rules-at-straits-of-malacca-and-singapore/ [Accessed May 2022].
IWC, 2016. *Information on recent outcomes regarding minimizing ship strikes to cetaceans (MEPC 69/10/3),* London: IMO.
Janik, V. M. & Sayigh, L., 2013. Communication in bottlenose dolphins: 50 years of signature whistle research. *Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology,* 199(6), pp. 479-489.
Jivén, K., Lammgård, C., Woxenius, J. & Fridell, E., 2020. *Consequences of speed reductions for ships,* Göteborg: Lighthouse.
La Manna, G., Manghi, M., Perretti, F. & Sara, G., 2016. Behavioral response of brown meagre (Sciaena umbra) to boat noise. *Marine Pollution Bulletin,* 110(1), pp. 324-334.
Leaper, R., 2019. The role of slower vessel speeds in reducing greehouse gas emissions, underwater noise and collision risk to whales. *Frontiers in Marine Science,* 6(Article 505).
Leaper, R., Renilson, M. R. & Ryan, C., 2014. Reducing underwater noise from large commercial ships: current status and future directions. *Journal of Ocean Technology,* Volume 9, pp. 50-69.
Lindsay, R. & Scott, M., 2010. *What are Phytoplankton?.* [Online] Available at: https://earthobservatory.nasa.gov/features/Phytoplankton [Accessed May 2022].

Luís, A. R., Couchinho, M. N. & dos Santos, M. E., 2014. Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. *Marine Mammal Science,* 30(4), pp. 1417-1426.

MacGillivray, A. & Li, Z., 2018. *Vessel Noise Measurements from the ECHO Slowdown Trial: Final Report. Document 01518, Version 3.0.,* Victoria: Jasco Applied Sciences for Vancouver.

Martin, E., 2021. France gears up to propose Mediterranean ship speed limits to protect whales. *TradeWinds,* 22 November.

Meijles, E. et al., 2021. Tracked to protect - Spatiotemporal dynamics of recreational boating in sensitive marine natural areas. *Applied Geography,* 130(102441).

Mikkelsen, L. et al., 2019. Long-term sound and movement recording tags to study natural behavior and reaction to ship noise of seals. *Ecology and Evolution,* 9(5), pp. 2588-2601.

Ministry of Oceans and Fisheries, 2019. *News Room - Vessel Speed Reduction (VSR) Program to Start December this Year.* [Online]
Available at: https://www.mof.go.kr/en/board.do?menuIdx=1491&bbsIdx=30629
[Accessed May 2022].

Mohcine, C. et al., 2018. Noise pollution limits metal bioaccumulation and growth rate in a filter feeder, the Pacific oyster Magallana gigas. *PLoS ONE,* 13(4).

Nedelec, S. et al., 2014. Anthropogenic noise playback impairs embryonic development and increases mortality in a marine invertebrate. *Scientific Reports,* 4(1), pp. 13-16.

Nolet, V., 2017. *Understanding Anthropogenic Underwater Noise, TP 15348 E,* Ottawa: Transport Canada.

Osterrieder, S. K., Kent, C. S. & Robison, R., 2017. Responses of Australian sea lions, Neophoca cinerea, to anthropogenic activities in the Perth metropolitan area, Western Australia. *Aquatic Conservation Marine and Freshwater Ecosystems,* Issue 27, pp. 414-435.

Popper, A. N., 2003. Effects of anthropogenic sounds on fishes. *Fisheries,* 28(10), pp. 24-31.

Popper, A. N. & Hawkins, A. D., 2018. The importance of particle motion to fishes and invertebrates. *The Journal of the Acoustical Society of America,* 143(1), pp. 470-488.

Popper, A. N. & Pilleri, G. E., 1985. Echolocation in Whales and Dolphins. *Trends in Neurosciences,* Issue 8, pp. 36-37.

Port of Amsterdam, 2020. *Adoption of the maximum speed on the North Sea Canal and on the Afgesloten IJ until the Stenen Hoofd at Amsterdam.* [Online]
Available at: https://www.portofamsterdam.com/en/announcement/adoption-maximum-speed-north-sea-canal-and-afgesloten-ij-until-stenen-hoofd-amsterdam
[Accessed May 2022].

Port of Long Beach, ongoing. *Incentives - Green Flag Program.* [Online]
Available at: https://polb.com/business/incentives/#green-flag-program
[Accessed May 2022].

Port of Vancouver, ongoing a. *2022 Haro Strait and Boundary Pass voluntary ship slowdown.* [Online]
Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/haro-slowdown/
[Accessed May 2022].

Port of Vancouver, ongoing b. *2022 Strait of Juan de Fuca voluntary inshore lateral displacement.* [Online]
Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/lateraldisplacement/
[Accessed May 2022].

Port of Vancouver, ongoing c. *2022 Swiftsure Bank voluntary ship slowdown trial.* [Online]
Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/swiftsure-bank-slowdown/
[Accessed May 2022].

Port of Vancouver, ongoing d. *ECHO Program projects and initiatives.* [Online]
Available at: https://www.portvancouver.com/environmental-protection-at-the-port-of-vancouver/maintaining-healthy-ecosystems-throughout-our-jurisdiction/echo-program/projects/
[Accessed May 2022].

Pörtner, H. O. & Farrell, A., 2008. Pphysiology and climate change. *Science,* 322(5902), pp. 690-692.

Quick, N. J. & Janik, V., 2012. *Bottlenose dolphins exchange signature whistles when meeting at sea,* s.l.: Proceedings of the Royal Society B: Biological Sciences, 279(1738), 2539–2545.

Rendell, L. E. & Whitehead, H., 2003. *Vocal clans in sperm whales (Physeter macrocephalus).* s.l., Proceedings of the Royal Society B: Biological Sciences, 270(1512), 225–231.

Riesch, R., Ford, J. K. B. & Thomsen, F., 2006. *Stability and group specificity of stereotyped whistles in resident killer whales, Orcinus orca, off British Columbia,* s.l.: Animal Behaviour, 71(1), 79–91..

Rolland, R. M. et al., 2012. Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B,* 279(1737).

Ross, D., 1976. *Mechanics of Underwater Noise,* New York: Pergamon Press, 375.

Slabbekoorn, H. et al., 2010. A noisy spring: The impact of globally rising underwater sound levels on fish. *Trends in Ecology & Evolution,* 25(7), pp. 419-427.

Stanley, J. A., Wilkens, S. & Jeffs, A., 2014. Fouling in your own nest: Vessel noise increases biofouling. *Biofouling,* 30(7), pp. 837-844.

Terhune, J., Stewart, R. E. A. & Ronald, K., 1979. Influence of vessel noises on underwater vocal activity of harp seals. *Canadian Journal of Zoology,* 6(57), pp. 1331-1338.

The Port of Los Angeles, ongoing. *Vessel Speed Reduction Program.* [Online]
Available at: https://www.portoflosangeles.org/environment/air-quality/vessel-speed-reduction-program
[Accessed May 2022].

Tknika, SEA Europe, industriAll Europe & Turku University of Applied Sciences, 2020. *D2.4.Forecasting trends & challenges for a 4.0 Shipbuilding Workforce in Europe,* s.l.: Upskilling Shipbuilding Workforce in Europe (USWE).

TNO, 2021. *Reduction of ship traffic emissions and underwater radiated noise - Part 2,* The Hague: TNO.

Transport Canada, 2020. *Understanding Anthropogenic Underwater Noise.* [Online]
Available at: https://tc.canada.ca/en/initiatives/oceans-protection-plan/understanding-anthropogenic-underwater-noise
[Accessed May 2022].

Vancouver Fraser Port Authority, 2020. *Vessel Noise Correlation Study, ECHO Program Study Summary,* Vancouver: Port of Vancouver.

Vancouver Fraser Port Authority, 2021. *Vessel Noise Correlation Study – Phase 2; ECHO Program Summary,* Vancouver: s.n.

Vanderlaan, A. & Taggert, C., 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. *Marine Mammal Science,* 23(1), pp. 144-156.

Velasquez Jimenez, L., Fakan, E. P. & McCormick, M. I., 2020. Vessel noise affects routine swimming and escape response of a coral reef fish. *PloS ONE,* 15(7).

VPO, 2019. *Speed through water – the missing piece of the vessel performance puzzle?.* [Online]

Available at: https://vpoglobal.com/2019/10/21/speed-through-water-the-missing-piece-of-the-vessel-performance-puzzle/
[Accessed May 2022].
WaddenZee.nl, 2010. *Snelvaren op de Waddenzee*. [Online]
Available at: https://www.waddenzee.nl/themas/duurzame-bereikbaarheid/scheepvaart/snelvaren-op-de-waddenzee
[Accessed May 2022].
Wale, M., Simpson, S. & Radford, A., 2013. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. *biology Lletters,* 9(2).
Weilgart, L., 2018. *The impact of ocean noise pollution on fish and invertebrates,* s.l.: Oceancare & Dalhousie University.
Weir, C. R., Frantzis, A., Alexiadou, P. & Goold, J., 2007. The burst-pulse nature of 'squeal' sounds emitted by sperm whales (Physeter macrocephalus). *Journal of the Marine Biological Association of the UK,* 87(01), p. 39.
Wilkens, S., Stanley, J. & Jeffs, A., 2012. Induction of settlement in mussel (Perna canaliculus) larvae by vessel noise. *Biofouling,* 28(1), pp. 65-72.
Winkler, C., Murphy, S. & Ritter, F., 2020. *Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database,* s.l.: International Whaling Commission.
World Maritime University, 2021. *Comprehensive impact assessment of short-term measure approved by MEPC 75 - full report on the literature review (MEPC76/INF.68),* s.l.: IMO.

A EEDI reduction factors

Table 13, gives the EEDI reduction factors for newbuild ships as specified in Resolution MEPC.328(76).

Table 13 - EEDI reduction factors (in percentage) relative to the reference line

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Mar 2022	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Apr 2022 and onwards	Phase 3 1 Jan 2025 and onwards
Bulk carrier	20,000 DWT and above	0	10		20		30
	10,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
Gas carrier	15,000 DWT and above	0	10	20		30	
	10,000 and above but less than 15,000 DWT	0	10		20		30
	2,000 and above but less than 10,000 DWT	n/a	0-10*		0-20*		0-30*
Tanker	20,000 DWT and above	0	10		20		30
	4,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
Containership	200,000 DWT and above	0	10	20		50	
	120,000 and above but less than 200,000 DWT	0	10	20		45	
	80,000 and above but less than 120,000 DWT	0	10	20		40	
	40,000 and above but less than 80,000 DWT	0	10	20		35	
	15,000 and above but less than 40,000 DWT	0	10	20		30	
	10,000 and above but less than 15,000 DWT	n/a	0-10*	0-20*		15-30*	
General Cargo ships	15,000 DWT and above	0	10	15		30	

Ship Type	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Mar 2022	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Apr 2022 and onwards	Phase 3 1 Jan 2025 and onwards
	3,000 and above but less than 15,000 DWT	n/a	0-10*	0-15*		0-30*	
Refrigerated cargo carrier	5,000 DWT and above	0	10		15		30
	3,000 and above but less than 5,000 DWT	n/a	0-10*		0-15*		0-30*
Combination carrier	20,000 DWT and above	0	10		20		30
	4,000 and above but less than 20,000 DWT	n/a	0-10*		0-20*		0-30*
LNG carrier***	10,000 DWT and above	n/a	10**	20		30	
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**		15		30
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**		20		30
	1,000 and above but less than 2,000 DWT	n/a	0-5*,**		0-20*		0-30*
Ro-ro passenger ship***	1,000 DWT and above	n/a	5**		20		30
	250 and above but less than 1,000 DWT	n/a	0-5*,**		0-20*		0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20		30	
	25,000 and above but less than 85,000 GT	n/a	0-5*,**	0-20*		0-30*	

* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

** Phase 1 commences for those ships on 1 September 2015.

*** Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 2.1 of regulation 2.

Note: n/a means that no required EEDI applies.

B EEXI reduction factors

Table 14, gives the EEXI reduction factors as specified in Resolution MEPC.328(76).

Table 14 - EEXI reduction factors (in percentage) relative to the reference line

Ship type	Size	Reduction factor
Bulk carrier	200,000 DWT and above	15
	20,000 and above but less than 200,000 DWT	20
	10,000 and above but less than 20,000 DWT	0-20*
Gas carrier	15,000 DWT and above	30
	10,000 and above but less than 15,000 DWT	20
	2,000 and above but less than 10,000 DWT	0-20*
Tanker	200,000 DWT and above	15
	20,000 and above but less than 200,000 DWT	20
	4,000 and above but less than 20,000 DWT	0-20*
Containership	200,000 DWT and above	50
	120,000 and above but less than 200,000 DWT	45
	80,000 and above but less than 120,000 DWT	35
	40,000 and above but less than 80,000 DWT	30
	15,000 and above but less than 40,000 DWT	20
	10,000 and above but less than 15,000 DWT	0-20*
General cargo ship	15,000 DWT and above	30
	3,000 and above but less than 15,000 DWT	0-30*
Refrigerated cargo carrier	5,000 DWT and above	15
	3,000 and above but less than 5,000 DWT	0-15*
Combination carrier	20,000 DWT and above	20
	4,000 and above but less than 20,000 DWT	0-20*
LNG carrier	10,000 DWT and above	30
Ro-ro cargo ship (vehicle carrier)	10,000 DWT and above	15
Ro-ro cargo ship	2,000 DWT and above	5
	1,000 and above but less than 2,000 DWT	0-5*
Ro-ro passenger ship	1,000 DWT and above	5
	250 and above but less than 1,000 DWT	0-5*
Cruise passenger ship having non-conventional propulsion	85,000 GT and above	30
	25,000 and above but less than 85,000 GT	0-30*

* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.