CLEANER SHIPPING

Focus on air pollution, technical solutions and regulation

THE DANISH ECOLOGICAL COUNCIL

CONTENT

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AIR POLLUTION FROM SHIPPING

About 90% of global cargo is transported by ships; shipping is thereby the key platform of the still increasing global trade. However, the high transport share leads to around 6 million barrels of oil being combusted in ship engines every day – corresponding to the oil export of Kuwait – thereby contributing with 2-2.5% of global anthropogenic CO_2 emissions.

Most ships use heavy fuel oil (HFO) that can contain up to 3.5% sulphur. However, in the specific SECAs (Sulphur Emission Control Areas), including seas around Denmark, a maximum of 0.1% sulphur is allowed, so lighter fuels are used. For comparison, road diesel in the EU can only contain 0.001% sulphur. Consequently, fuel used by ships in the Baltic Sea can contain 100 times more sulphur than cars crossing the bridge between Denmark and Sweden.

Ideal combustion in ship engines oxidises all carbon and sulphur into CO_2 and sulphur oxides (mainly sulphur dioxide, SO_2). At the same time, free nitrogen (N_2) in the combustion air is oxidised into nitrogen oxides (NO_x) inside the engine. However, complete combustion does not occur. Hence, the flue gas contains carbon monoxide, polycyclic aromatic hydrocarbons, volatile organic compounds and particulate matter. High sulphur contents in the fuel oil increase emissions of SO_2 and particulate matter. The most important pollutants in relation to health damage are SO_2, NO_x and fine particles ($PM_{2.5}$), as these pollutants have a long lifetime and thereby significantly increase air pollution on land. However, ultrafine particles ($PM_{0.1}$) from ships in ports can cause work related heath problems for port workers and significant local pollution. This is especially the case, when cruise ships use their engines for energy generation during long port calls.

The use of fuel oil thereby emits the same air pollutants as traditionally emitted by road vehicles, power plants, etc. However, most road fuel is de-sulphurised today, and vehicles and power plants have efficient flue gas cleaning systems in most of the world. No comparable regulations apply to shipping. However, in recent years the IMO (International Maritime Organization) has adopted regulation that will reduce emissions from shipping.

Heavy fuel oil (HFO) is a waste product from refineries. When light hydrocarbons used for jet fuels, gasoline and diesel, etc. are distilled from crude oil, the remaining parts are used as HFO for ships and asphalt. HFO is extremely viscous and has a high content of sulphur. HFO is heated under high pressure before being combusted in ship engines. Today, most fuel oil is combusted at sea without any flue gas cleaning.

DCE (Danish Centre for Environment and Energy) at Aarhus University estimates that air pollution from shipping causes about 50,000 premature deaths in Europe every year. The associated health costs are above USD 80 billion (US dollars). On top of this comes damage to nature, crops, buildings, etc. In 2015, the sulphur limit in SECAs was further reduced. This brought positive effects in the SECAs, but has not reduced health damage significantly on a global scale. However, in parts of the SECA, ship emissions are still responsible for eutrophication and acidification.

The seas around Denmark have around 100,000 passages (large ships) every year. Large container ships only sail 5-10 meters per litre of fuel. Consequently, huge amounts of fuel are combusted in the seas around Denmark, resulting in serious air pollution. Hence, NO_x emissions from shipping in the seas around Denmark are much higher than pollution from all domestic sources in Denmark. DCE at Aarhus University estimates that air pollution from shipping causes about 450 premature deaths every year in Denmark along with socio-economic health costs of around USD 670 million. The tightening of the SECA regulation in 2015 has only reduced health damage caused by shipping by about 15% in Denmark: most health damage incidents are caused by NO_x emissions, and emissions outside the North European SECA also cause health damage in Denmark.

This publication focuses on air pollution with CO_2, SO_2, NO_x and fine/ultrafine particles from shipping, technical solutions, existing regulation, the need for further regulation and enforcement. The purpose is to inspire decision-makers and other key stakeholders to implement more ambitious regulation as well as enforcement to reduce air pollution from shipping to the benefit of shipping as a business, the climate, public health and nature. Finally, this publication is intended for teaching in natural science classes.

Shipping leads to a number of other serious environmental impacts, e.g. fauna pollution with invasive species, risk of oil pollution, environmental and social problems due to uncontrolled ship dumping in third world countries, etc. However, these issues are not discussed in this publication.

ADVERSE EFFECTS

Shipping is not regulated as strictly as most other sectors, when it comes to air pollution. The main reasons are that shipping is an international business and that ships often sail in international seas, thereby only being regulated by international law. The easy reflagging of ships allows to freely choosing under which flag ships sail. If one nation tries to regulate shipping through national legislation, its ships will just reflag to nations with less strict environmental legislation.

International regulation of shipping is decided by the IMO. However, as flag states have very different perceptions of environmental challenges and global warming, IMO decisions have traditionally been slow and unambitious when trying to regulate these issues. However, for the last couple of years there has been softening on several accounts and decisions have been taken to further reduce emissions of CO_2 and health damaging air pollution from shipping. At the same time, further CO_2 reductions from shipping are discussed intensely, not least due to pressure from the EU. From an environmental perspective, however, the adopted regulation (see page 21) is not ambitious, but should be seen as the best possible compromise between many conflicting interests in the IMO.

Table 1 shows important types of air pollutants from shipping, adverse effects connected to them as well as costs of health damage in Europe due to emissions in and outside the North European SECA. It should be emphasised that as the value of lost human lives is being significantly revalued these years, the values used in the table are conservative and probably significantly underestimate the true costs.

Table 1: Damage and health costs due to air pollution from shipping (2018 prices)

	CO_2	SO_2	NO_x	Particles
Direct health damage		X	X	X
Indirect health damage [1)]		X	X	
Global warming	X			X [2)]
Acidification of the oceans	X			
Acid rain on land		X	X	
Eutrophication			X	
Health damage outside the SECA (USD/kg) [3)]		16.5	13.5	26.5
Health damage outside the SECA (USD/tonne fuel oil) [3), 4)]		830	935	185
Health damage in the SECA (USD/kg) [3)]		18.5	21.5	56
Health damage in the SECA (USD/tonne fuel oil) [3), 4)]		36.5	1515	56

1) When transformed into health damaging secondary particles in the atmosphere.
2) Black carbon contributes to global warming and accelerates melting of the icecaps – particularly in the Arctic.
3) As the value of lost human lives is being reconsidered and tends to be increased considerably compared to the assumptions underlying the table, the values stated are conservative.
4) By burning one tonne of HFO outside SECA about 50kg of SO_2, 70kg of NO_x and 7kg of particles are emitted, while burning one tonne of low-sulphur fuel oil in SECA emits about 2kg of SO_2, 70kg of NO_x and 1kg of particles.

Source: Calculated from data obtained from DCE at Aarhus University with regards to the North European SECA.

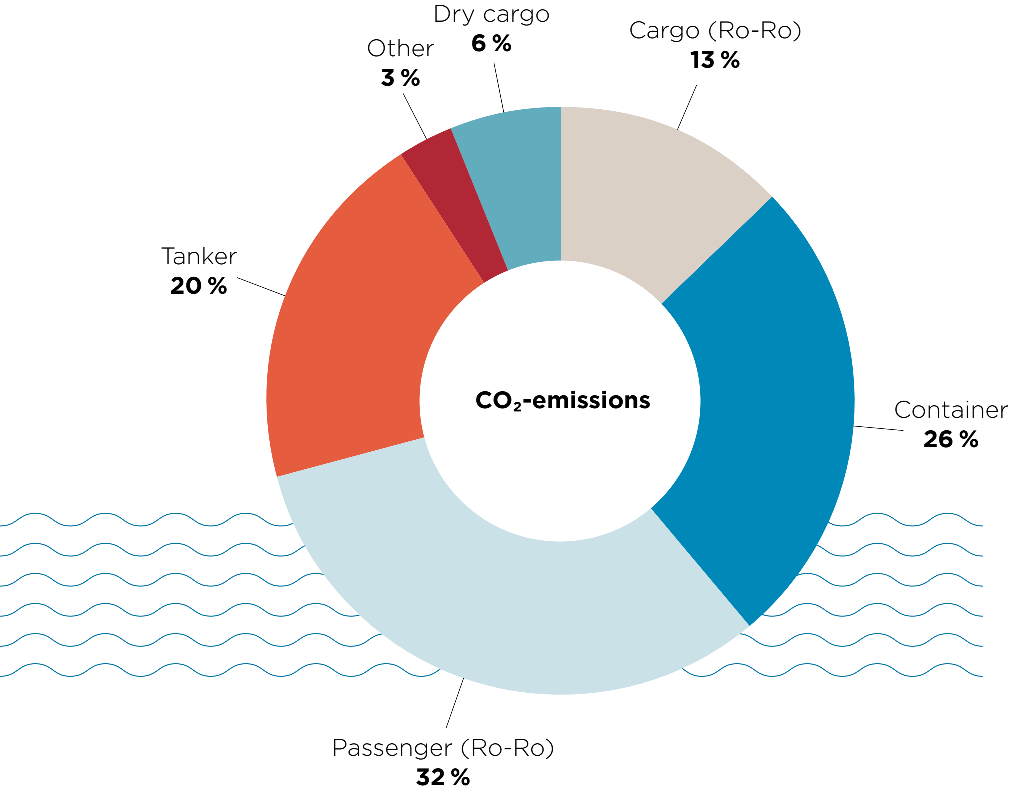


Figure 1: CO_2 emissions from shipping in the seas around Denmark in 2011

In table 1, average health costs (externalities) in Europe from ship emissions of SO_2, NO_x and fine particles in the northern hemisphere inside and outside the North European SECA are calculated per kilogram of pollutant and per tonne of combusted fuel oil. In addition to health damage, costs due to damage on crops, buildings and nature should be added. It is not possible to make equivalent cost calculations of impacts and damage (externalities) related to CO_2, since long-term impacts on society and public health from global warming are highly unpredictable. Hence, in addition to all the predictable damage to food production, health and biodiversity, several areas are at risk of becoming uninhabitable due to intensified drought, flooding and overheating, etc. Furthermore, it is impossible to estimate indirect costs due to global warming, such as the costs associated with the integration of many millions of climate refugees in Europe and, consequently, an enhanced risk of wars and national isolation/protectionism.

Nevertheless, a pricing of CO_2 emissions is often seen: however, such prices are the price of CO_2 emission allowances or the cost of reducing one tonne of CO_2. This cost is typically set to USD 30-50 per tonne of CO_2. However, this is not the costs of damage caused by emitted CO_2 but the costs of avoiding CO_2 emissions. The attempts made to estimate the actual costs of CO_2 due to the effects of global warming arrive – with great uncertainty – at far higher amounts. Regardless of the lack of valuation of CO_2 impacts, there is a need to reduce both the harmful air pollution and CO_2 emissions from shipping.

Health costs per kilogram of emitted pollutants in the northern hemisphere are higher inside the North European SECA than outside the SECA (cf. table 1), as combustion inside the SECA is geographically closer to densely populated areas. Combustion of HFO outside the SECA, on the contrary, has the highest total health costs, since this fuel oil contains significantly more sulphur.

Furthermore, the table shows that total health damage caused by burning one tonne of fuel oil is around USD 2,000 outside the SECA and around USD 1,600 in the SECA. By comparison, HFO costs about USD 400 per tonne, while low-sulphur fuel oil for use in SECAs costs approximately USD 625 (January 2018). If shipowners had to pay for health damage caused by their air pollution, the price would increase six-fold outside SECAs and more than triple in SECAs, respectively. Shipowners would in such case immediately make a switch from HFO to low-sulphur fuel oil everywhere, and they would install efficient flue gas cleaning. However, since society and the public pay for the resulting health damage, this does not happen. Lack of internalisation of externalities thus causes a traditional market failure, where ships pollute much more than the socio-economic optimal from an economic point of view.

Figure 1 shows an estimate of CO_2 emissions from shipping in seas around Denmark in 2011 on the basis of ship type. In outline, the relative distribution of SO_2, NO_x and particles follows the distribution of CO_2 emissions by ship type, as all four pollutants are caused by burning fuel oil.

Carbon dioxide

Globally, shipping emits about 800 million tonnes of CO_2 per year, which is about 2-2.5% of anthropogenic CO_2 emissions. About 80% originates from cargo ships, while 20% is due to fishing boats, passenger ships, etc. In addition to global warming, the increasing CO_2 concentration in the atmosphere contributes to acidification of the oceans, as the concentration of carbonic acid (H_2CO_3) increases. Acidification of oceans together with increasing sea temperature due to global warming will have fatal consequences for several of the most amazing ecosystems, e.g. unique coral reefs.

Although shipping emits almost as much CO_2 as France, Italy and the Czech Republic together, CO_2 emissions from shipping are still not included in any directly binding international regulation. Theoretically, shipping is included in the Paris agreement, where all polluters must contribute to reductions to limit the anthropogenic rise in temperature to a maximum of 2°C above preindustrial levels. However, since emissions from international shipping cannot be assigned to a specific nation, the UN cannot impose emissions reduction obligations as it is done with, e.g. power plants. Thus, CO_2 emissions from shipping are not included in national CO_2 statistics. Shipping gets the status of an independent, diffuse and global sector that must be regulated as such through the UN by the IMO or UNFCCC.

It is a specific challenge for shipping that the increasing globalisation entails a steady increase in ship transport by 2050 and, hence, is expected to significantly increase CO_2 emissions from the sector. However, the global CO_2 emissions are supposed to be at least halved by 2050 compared to 1990 levels to live up to the Paris agreement. Meanwhile, CO_2 emissions from shipping have already increased significantly since 1990. If the increase continues and all other sectors reduce their CO_2 emissions in compliance with the Paris agreement, a worst case scenario would be that shipping emits 10% of all anthropogenic CO_2 in 2050. This calls for urgent CO_2 reductions from shipping. Finally, it is worth mentioning that insourcing through automation and technology leaps such as 3-D printing can reduce the need for shipping activities and the expected CO_2 emissions from the sector towards 2050 despite an increasing globalisation.

Sulphur dioxide

Emissions of sulphur dioxide from shipping in the seas around Denmark make up around 60% of emissions from all Danish land-based pollution sources. If Denmark had not been geographically placed inside a SECA, the emission level from shipping would have been approximately 15 times higher than all Danish land-based sources. The sulphur content in fuel oil is regulated by the IMO both in and outside SECAs (see page 21).

A substantial part of SO_2 in the flue gas is transformed into sulphate (SO_4^{2-}) in the atmosphere, e.g. by the formation of sulphuric acid (H_2SO_4) creating acid rain, which contributes to, among other things, forest decline. Moreover, SO_2 is a directly health hazardous gas. However, SO_2 from shipping mainly contributes to health damage through hazardous secondary fine particles formed through atmospheric reactions between SO_2 and other pollutants (primarily ammonia).

Figure 2 shows emissions from shipping in Danish seas. The main shipping routes are clear.

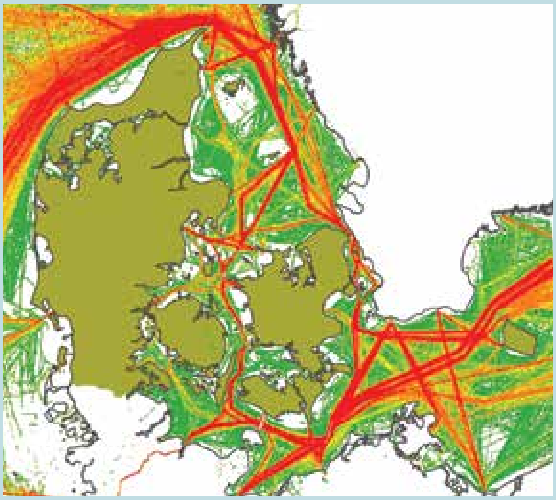


Figure 2: Geographic distribution of emissions from shipping in Danish seas

High emissions.

Average emissions

No emissions

Nitrogen oxides

Emissions of NO_x from shipping in the seas around Denmark are approximately 1.5 times higher than emissions from all Danish land-based sources. Emissions of NO_x are regulated by the IMO (see page 22). NO_x emissions will, however, only decrease significantly in the long term inside NO_x Emission Control Areas (NECAs) as the current regulation is weak.

NO_x emissions consist mainly of nitrogen monoxide (NO) and, to a lesser extent, nitrogen dioxide (NO_2). NO_x can be transformed into nitric acid (HNO_3) in the atmosphere and become acid rain contributing to forest decline. NO_x enhances the formation of health damaging smog. Simultaneously, a substantial part of NO reacts and becomes directly health damaging NO_2. However, NO_x primarily contributes to health damage in the form of hazardous secondary fine particles formed through atmospheric reactions between NO_x and other pollutants (primarily ammonia). Finally, NO_x can be deposited in low-nutrient ecosystems where nitrogen acts as a fertiliser and destroys the unique low-nutrient ecosystems, which are the habitat for a wide range of the planet's rare flora and fauna species.

Particles

Emissions of fine particles from shipping in the seas around Denmark correspond to approximately 15% of emissions from Danish land-based sources. Emissions are not regulated by the IMO.

Particles in air are classified by size. *Fine particles* ($PM_{2.5}$) are particles with a diameter less than 2.5 micrometres. They are measured in particle mass per volume air, typically in micrograms per cubic metre. They are long lived and therefore cause long-range transboundary air pollution. *Ultrafine particles* ($PM_{0.1}$) are particles with a diameter less than 0.1 micrometre (100 nanometres). They are measured in number of particles per volume air, typically number per cubic centimetre. They are short lived and mainly cause local air pollution. Fine and ultrafine particles are both emitted directly from ship engines as primary particles that often contain a high level of soot (black carbon). In addition, secondary fine particles are formed from inorganic contaminants through chemical reactions in the air, e.g. SO_2, NO_x and ammonia (see above) and as organic condensate particles.

Particles increase the risk of cancer, cardiovascular diseases, blood clots and respiratory diseases, all of which contribute to premature death. As fine particles are spread over long distances, they contribute to health damage both when they are emitted at sea and in ports. By contrast, ultrafine particles are primarily a problem when emitted in port areas.

Fine particles that consist of black carbon contribute significantly to global warming, since they are transported to – and deposited on – the Arctic ice sheet. Here, they absorb sunlight and heat the ice, thereby accelerating the melting of the ice and reinforcing global warming. Most recent studies show that black carbon is the second-most important cause of Arctic warming and melting of the ice after CO_2. The closer to the icecap the particles are emitted, the greater share is deposited on it. In the Arctic area shipping is the greatest regional source of black carbon emissions. However, shipping only contributes to a limited extent to the deposition of black carbon on the ice, as the main contribution is long-range transboundary pollution coming from wood stoves, diesel traffic, power plants, etc. in Canada, Europe, Russia, etc. The temperature in the Arctic is increasing with double speed compared to the rest of the planet, and the size of the sea ice is currently record low. This has opened up for ships taking a shortcut through the Arctic, which increases emissions of black carbon near the icecap – and

increases the risk of oil spill in some of the most vulnerable ecosystems where a clean-up is practically impossible. A regulation of black carbon from shipping in the Arctic is therefore urgently needed.

Ultrafine particles from cruise ships and ferries at berth can be a specific problem both in relation to occupational health for port workers and for the population in nearby residential and public areas. These ships often use ports close to large cities and emit high amounts of ultrafine particles. For ferries, it is in particular frequent arrivals and departures that contribute to the pollution, whereas cruise ships are large energy consuming hotels that often have long stays at berth while producing energy (heat and electricity) with their own extremely polluting engines and fuel. Furthermore, cruise tourism is dramatically growing these years, and at the same time many ports are progressively expanding with new residential and public areas. Local air pollution from ferries and cruise ships at berth can be eliminated if ships use land power (*cold ironing*) instead of their own engines.

In figure 3 air quality measurements of ultrafine particles from a cruise ship at *Oceankaj* in the Port of Copenhagen can be seen, both near the ship (15-20m from the ship) and 50-100m downwind the ship. Measurements were made with P-Trak's from TSI.

Figure 3 shows that no measurement goes below 20,000 particles per cm^3 and that the average pollution reaches a level of about 30-40,000 particles per cm^3 both near the ship and 50-100m downwind the ship. This should be compared to the typical particle level at the dock, which is about 2,000 particles per cm^3 when there are no cruise ships in the port area. An average pollution level of around 35,000 particles per cm^3 corresponds to the pollution level found near the most polluted streets of Copenhagen during rush hour on a calm day. When the same high concentrations are measured 50-100m downwind from a ship under conditions with relatively strong winds (4-4.5 $^m/_s$ at measurement height) it shows that the pollution plume from the cruise ship is very intense and can reach much of the port area. By way of comparison, pollution with ultrafine particles from road traffic 50-100m downwind the most polluted streets in Denmark will hardly be measurable at a local wind speed of 4-4.5 $^m/_s$ due to dilution.

Figure 3: Air pollution with ultrafine particles from cruise ships at *Oceankaj* in Port of Copenhagen.

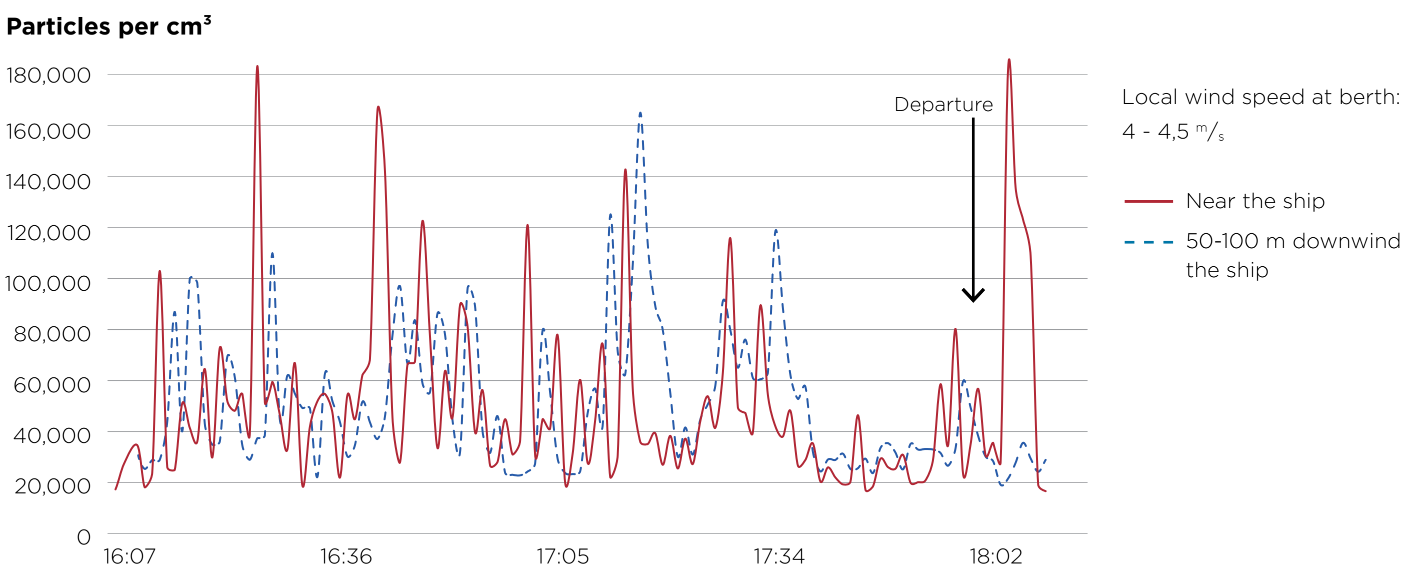


Table 2: Emissions from shipping compared to Danish land-based sources in 2018

Emissions in tonnes	SO_2	NO_X	Fine particles
Shipping in the northern hemisphere	1,500,000	3,355,000	240,000
Shipping in the North Sea and the Baltic Sea	29,000	955,000	13,000
Shipping in the seas around Denmark	6,000	173,000	2,500
Danish land-based air pollution sources	10,000	114,000	20,000

Source: Calculated from data obtained from DCE at Aarhus University.

Table 3: Health damage due to air pollution from shipping in 2018

	Northern hemisphere		North Sea and Baltic Sea	
	Denmark	Europe	Denmark	Europe
YOLL [1]	4,600	570,000	3,500	140,000
Respiratory disease	280,000	32,000,000	225,000	7,900,000
Sick days	430,000	50,000,000	350,000	12,600,000

[1] YOLL: Years of lost living (about ten years of lost living is the same as a premature death).

Source: Calculated from data obtained from DCE at Aarhus University.

Table 2 shows emissions of SO_2, NO_X and fine particles from international shipping in the northern hemisphere and shipping in the North Sea and the Baltic Sea compared to emissions from shipping in the seas around Denmark and from all Danish land-based pollution sources.

Table 2 shows that the SO_2 and particle emissions from shipping in the northern hemisphere sum up to 50 and 20 times as high as the ship emissions in the North Sea and the Baltic Sea, respectively, while the NO_X pollution is only about 3.5 times as high. This is due to lower sulphur content in the fuel used in the SECA in the North Sea and the Baltic Sea, which reduces particle emissions as well. Further, it is seen that the NO_X pollution from shipping in the seas around Denmark exceeds the pollution from all Danish land-based pollution sources.

Table 3 shows the health damage caused by the emissions of SO_2, NO_X and fine particles from shipping in the northern hemisphere and in the Northern Sea and the Baltic Sea for Denmark and Europe. The health damage is estimated based on knowledge of where the pollution is emitted, the dispersion and transformation of the pollution in the atmosphere, the dose-response correlation between air pollution and health damage as well as knowledge about the size of population exposed to the pollution.

From table 3 it is seen that the pollution from shipping in the northern hemisphere causes four times as many health damage incidents across Europe compared to the pollution in the North Sea and the Baltic Sea. In Denmark, on the contrary, 80-90% of the health damage incidents caused by pollution from shipping are caused by emissions in the North Sea and the Baltic Sea. This illustrates that, despite of the SECA covering all seas around Denmark, shipping in these seas continues to cause huge health damage.

Table 4: Health costs in Europe due to air pollution from shipping in 2018

	Health costs in Europe (billion USD)			
	SO_2	NO_x	Fine particles	Total
Shipping in the northern hemisphere	25	45	6.5	**76.5**
Shipping in the North Sea and the Baltic Sea	0.5	20.5	0.5	**21.5**

Source: Calculated from data obtained from DCE at Aarhus University.

Table 4 shows the socio-economic costs due to health damage from air pollution from shipping estimated for Europe and divided on different pollutants.

From table 4 it can be seen that health damage from pollution from shipping in the northern hemisphere sums up to a yearly cost of USD 76.5 billion in Europe. Likewise, it is seen that NO_x causes the largest total cost – particularly in the North Sea and the Baltic Sea, where NO_x accounts for 95% of total costs related to air pollution from shipping. This is because the sulphur content in the fuel oil is significantly lower in the Baltic Sea and large parts of the North Sea due to the SECA.

In Denmark, socio-economic costs due to air pollution from shipping in the northern hemisphere amount to about USD 0.65 billion a year, of which around 80-90% is caused by shipping in the North Sea and the Baltic Sea. By comparison, air pollution from all Danish land-based pollution sources sums up to around USD 1.33 billion a year. Air pollution from shipping thereby causes health damage and socio-economic costs in Denmark corresponding to around half of all Danish land-based air pollution sources. It should be noted that damage from ultrafine particles is not included in these estimates.

Climate wins, environment loses

If land-based transport per tonne of cargo is compared to shipping, cargo transported by train emits 2-7 times more CO_2 while trucks emit 5-15 times more CO_2. In terms of global warming, shipping is thereby a favourable mode of transport. However, as shipping emits several hundred times more SO_2 and more than 50 times more particles than modern trucks per tonne of transported cargo, shipping causes serious health and nature damage as well.

From a health perspective, shipping is therefore not the best mode of transport. However, shipping has several other advantages compared to land-based transportation such as less noise exposure of the population, fewer traffic accidents and cheap infrastructure. On the other hand, a large share of transportation would not occur at all if it was not for extremely cheap shipping. Therefore, it does not always make sense to only compare alternative modes of transport. *No transport* is, all things being equal, preferable from a purely environmental perspective. It is recognised, however, that international shipping can be seen as a precondition for development and a more even distribution of resources.

All new trucks in the modern part of the world use low-sulphur fuel, which contains about 100 times less sulphur than the ship fuel used inside SECAs and 2,500 times less sulphur than the ship fuel used outside SECAs. Furthermore, modern trucks have efficient NO_x removal and particle filters. Hence, weak regulation gives shipping competitive advantages at the expenses of trains and trucks.

The solution is, however, not to stop global trade. Attempting to limit transportation is a possibility, but it seems more reasonable to reduce air pollution from shipping converting shipping to a green mode of transport. However, this requires focused efforts technically and politically. Fortunately, several technical solutions have been developed that can minimise air pollution from shipping. Most technical solutions for shipping have much lower reduction costs than if further reductions were to be implemented on land-based pollution sources. This is due to the fact that significant efforts to reduce air pollution from land-based sources have already been made in most parts of the world, while astonishingly little has been done to reduce air pollution from shipping. Hence, the relatively high degree of air pollution from shipping is the result of lack of political action.

TECHNICAL SOLUTIONS

There are four types of technical solutions:

1. Reduced fuel consumption.

2. Use of cleaner fuel.

3. Reduced engine pollution.

4. Flue gas cleaning.

Several technical solutions have been developed to reduce emissions of CO_2, SO_2, NO_x and particles from shipping. As shown below, a combination of solutions can significantly reduce CO_2 emissions and minimize SO_2, NO_x and particle emissions in the short term. In the long term, new larger ships and cleaner fuels can make shipping the *green* transport of the future.

Reduction costs for implementing technical solutions are often many times lower than the costs of health damage caused by air pollution (costs of no actions). Thus, many solutions are beneficial from a socio-economic point of view, as society saves (earns) many millions of dollars, every time one million is invested in flue gas cleaning. As an example, sulphur regulations inside the SECAs have a reduction cost of about USD 4 per kg of SO_2 due to higher fuel prices, while the avoided health damage costs are about USD 18.5 per kg of SO_2 removed, i.e. the profit is 4-5 times higher than the costs. Additionally, a significant particle reduction is automatically achieved. For the 2020 regulation outside SECAs, a reduction cost of USD 2 per kilogram of SO_2 is expected, while the avoided health damage costs are USD 16.5 per kilogram. For NO_x, the reduction cost lies between USD 0.2-2.50 (depending on ship type and flue gas cleaning technology) per kilogram of NO_x, whereas the avoided health damage costs amount to USD 13.5-21.5 per kilogram of NO_x. However, without regulation shipowners have no incentives to pollute less, as health and nature damage is paid by society and is thus invisible to shipowners. Therefore, pollution from shipping must be regulated to realise the benefits.

There are four types of technical solutions:

1. Reduced fuel consumption.
2. Use of cleaner fuel.
3. Reduced engine pollution.
4. Flue gas cleaning.

Some of the solutions can be combined, but reductions do not necessarily sum up. Furthermore, not all solutions can be used on all ships. The largest reductions can be achieved on new ships.

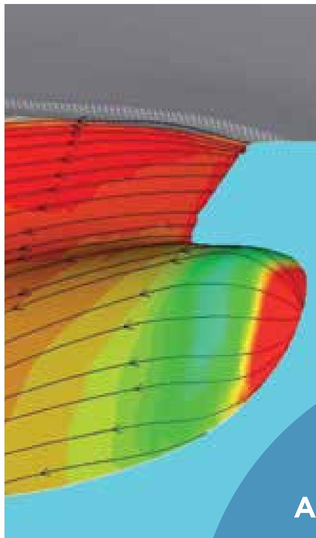
Reduced fuel consumption

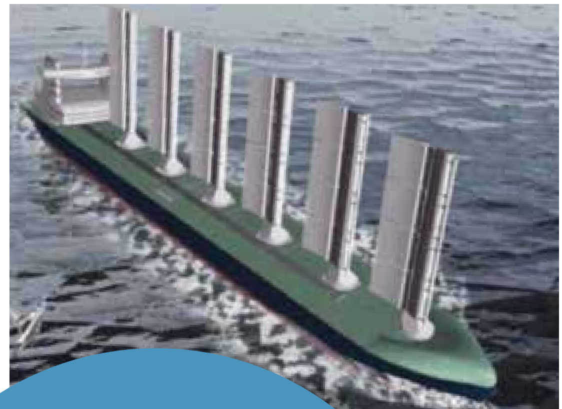
Fuel consumption can be reduced through several operational actions; including better use of capacity and logistics (route optimisation) combined with maintenance of the hull, propeller(s) and engines along with optimal sailing in respect to the weather and the physical ship characteristics. Furthermore, scheduled arrival may avoid waiting (on idle) for permission to enter ports. Finally, the speed of a ship has a significant influence on fuel consumption. By reducing speed, substantial fuel savings can be achieved. Reduced speed will, however, require more ships (more capacity), if transport capacity must be upheld since the duration of transport between ports increases. Nevertheless, fuel savings of 20-25% net are often achieved with reduced speed (slow steaming). Reduced speed increases flexibility as well, since the speed can be increased when unforeseen delays occur. This increases the probability of scheduled arrival. Also, reduced speed will increase the demand for ships in order to maintain the transport capacity, which can strip away some of the existing overcapacity in the industry and bring freight rates up to an economically sustainable level. This would enable investments in flue gas cleaning technologies and new, improved ships. In the long term, larger ships with improved engines and an energy-efficient design will further reduce fuel consumption, however, not enough to compensate for an increase in fuel consumption due to increased shipping.

In an ideal world, the potentials of operational measures are exploited to an extent equivalent to the economic benefits of the associated fuel savings. If the price of fuel increases, savings increase and the potentials of operational measures will be applied to a greater extent. Hence, in times with high fuel prices, slow steaming has been implemented. However, profitable operational measures are not fully utilised due to various market disturbances.

There are several options to reduce fuel consumption.

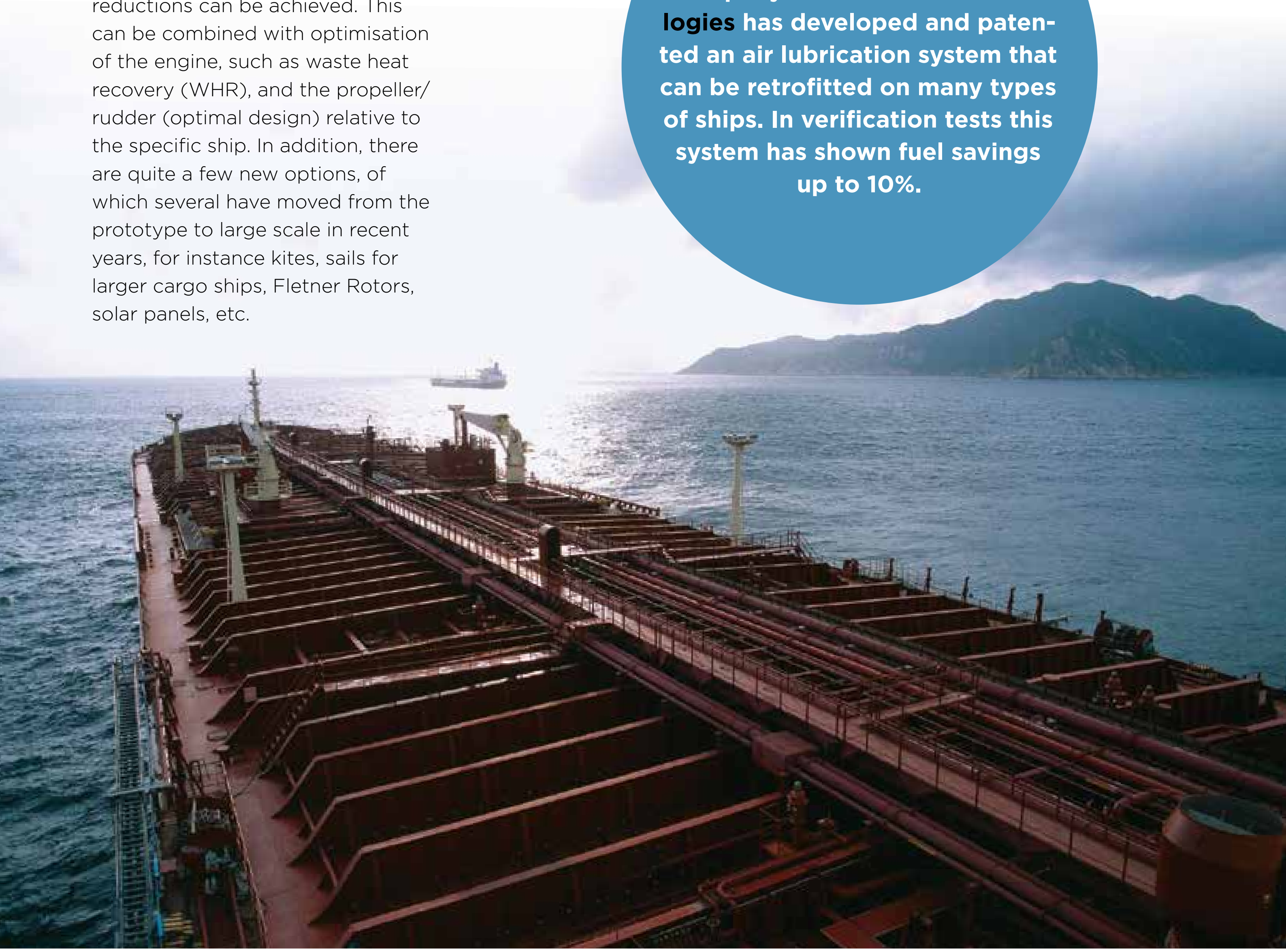
Source: Force Technology





By minimising water, wave and wind resistance of the hull through better ship design, new types of coating and by releasing air bubbles under the hull (*air lubrication*), further fuel reductions can be achieved. This can be combined with optimisation of the engine, such as waste heat recovery (WHR), and the propeller/rudder (optimal design) relative to the specific ship. In addition, there are quite a few new options, of which several have moved from the prototype to large scale in recent years, for instance kites, sails for larger cargo ships, Flettner Rotors, solar panels, etc.

As a specific example, the company Silverstream Technologies has developed and patented an air lubrication system that can be retrofitted on many types of ships. In verification tests this system has shown fuel savings up to 10%.



Cleaner fuel

By using cleaner fuels, pollution can be significantly reduced. This concerns both well-known fuels such as liquefied natural gas (LNG) and low-sulphur fuel containing 0.1% of sulphur, but also other sources of energy such as electricity (especially ferries and cruise ships at berth) and in the long term fuels such as road diesel, hydrogen, methanol, biofuels, etc. In the longer term perspective, LNG could be replaced by liquid biogas (LBG).

Environmental benefits of the individual fuels depend on many factors, including whether only emissions from the ship are considered, or a life-cycle perspective is applied where the production of fuel is taken into account as well. Evidently, there is a big difference between natural gas and biogas, whether electricity and hydrogen are produced from coal or wind power, whether biofuels are produced from food or waste, etc. In addition, emissions of unburned methane from the engines (*methane slip*) can have a very important impact on the climate calculation, since methane has a global warming potential (GWP) 25 times higher (100 years' time horizon) than CO_2. Furthermore, auxiliary fuel (if engines are not pure gas engines) can reduce the environmental potentials. Finally, whether the fuel is used in a 2-stroke or a 4-stroke engine can make a significant difference.

Table 5 shows reductions from the ship stack when using LNG, low-sulphur fuel oil and electricity (ferries and cruise ships at berth) compared to traditional HFO containing around 2.5% of sulphur. The benefits of LNG depend on engine technology. It is possible to eliminate methane slip (assumed in the table) in some engines. However, there is a general disagreement in literature on the actual reductions using LNG, which explains the intervals in the table.

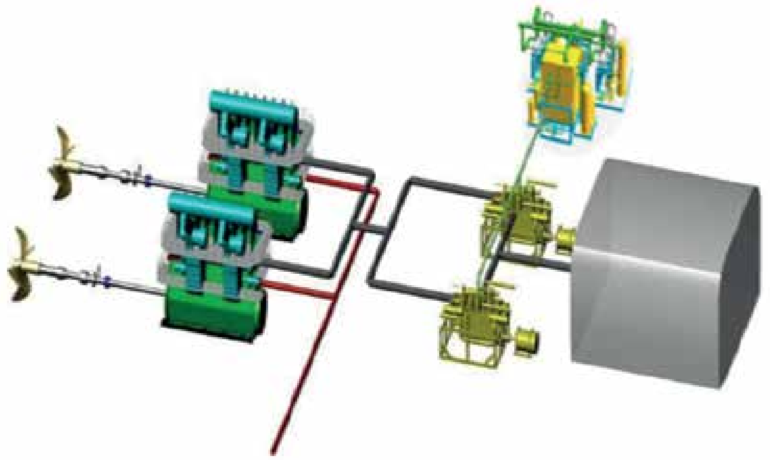
Low-sulphur fuel oil is today required inside SECAs. From 2020, a global regulation of a sulphur content of maximum 0.5% will come into force outside SECAs (see page 21), and this will reduce health and nature damage from shipping significantly. However, as shown in table 5, it will not result in a significant reduction in NO_X emissions, which is the most harmful type of air pollution from shipping (cf. table 4, page 11).

Table 5: Pollution reductions from the engine due to cleaner fuels (in percent)

	Engine	CO_2	SO_2	NO_X	Particles
Liquified Natural Gas (LNG)	2-stroke	20-25 [1]	> 90 [2]	> 20	40-95 [2]
	4- stroke	20-25 [1]	> 90 [2]	50-90	40-95 [2]
Low-sulphur fuel oil, SECA (0.1% sulphur)		0	95	5-10	35-85
Low-sulphur fuel oil, global 2020 (0.5% sulphur)		0	80	< 10	?
Electricity (ferries & cruise ships) [3]		100	100	100	100

1) It is assumed that the release of unburned methane escaping through the stack is eliminated.
2) Depending on sulphur content and auxiliary fuel/lubrication oil used.
3) In the EU where CO_2, SO_2, NO_X and fine particles from power plants are limited by emission allowances.
?: Depends on the type of fuel that is used to comply with the 2020 regulation of maximum 0.5% sulphur.

Source: General literature review



CO_2 and NO_x emissions can be significantly reduced by using larger and more efficient engines.

Source: MAN Diesel & Turbo

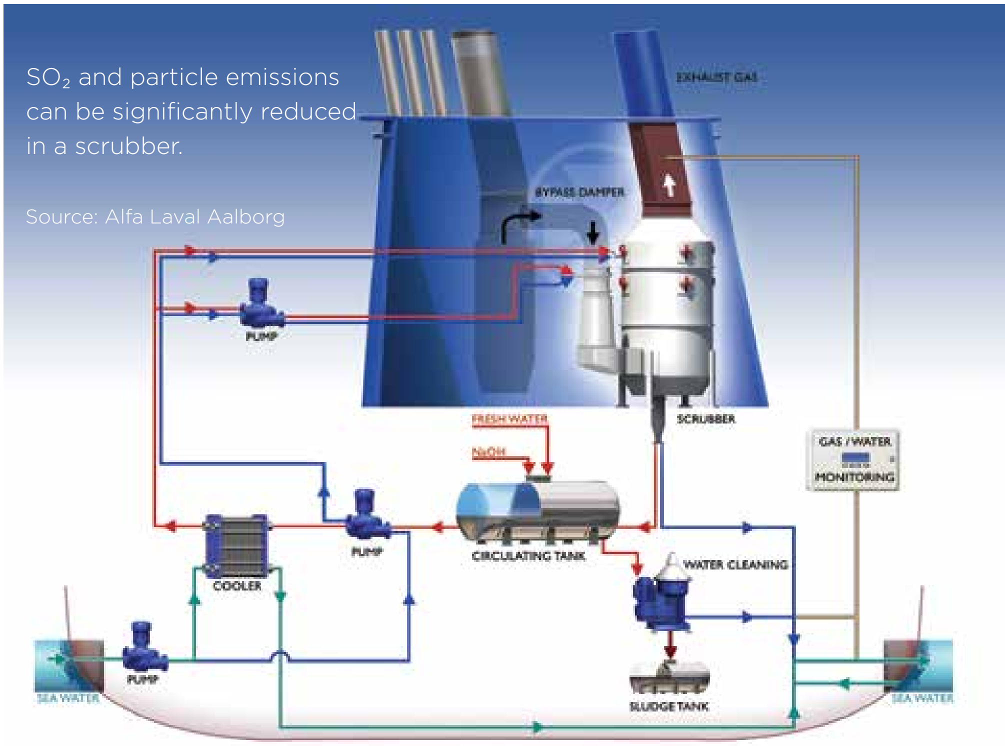
Cleaner fuel has several other benefits. Liquid gas and electricity eliminate the risk of oil spill (except for auxiliary fuel/lubrication oil and cargo). Low-sulphur fuel oil reduces the risk of long-term effects of oil spills. This is particularly important in the Arctic, where often there is no immediate possibility for clean-up after oil spills, where oil pollution slowly decomposes due to darkness and low temperatures, and where oil pollution causes long-term damage on the unique and sensitive ecosystems. Finally, low-sulphur fuel oil will enhance the operation of particle filters for ships, which can almost eliminate emissions of black carbon from shipping.

Better engine technology

For the last 50 years, the consumption of fuel oil per container per nautical mile has been reduced by more than 80% through the development of larger engines (for larger ships) with increasing efficiency. This development will continue to some extent, however, at a more subtle pace as older and smaller ships are replaced with new and larger ones. The optimisation of engines continues, among other things, with the development of systems utilising waste heat (WHR). Further, a low-NO_x valve for 2-stroke engines has been developed, which, without increasing fuel consumption, reduces the engine's NO_x emissions by 10-20% and, at the same time, reduces particle emissions. Exhaust Gas Recirculation (EGR), where part of the flue gas is recirculated through the engine, has proven to be an effective method to reduce NO_x emissions. EGR can reduce NO_x emissions from 2-stroke engines by more than 80%. The reduction achieved by EGR on 4-stroke engines is around half of that.

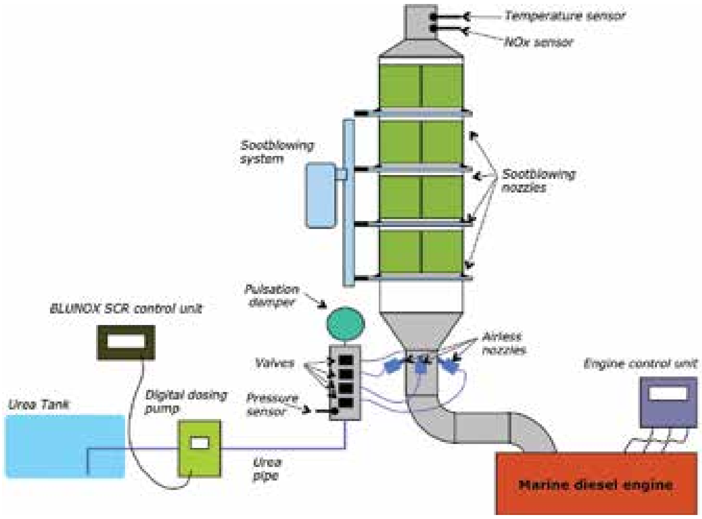
Flue gas cleaning

Flue gas from ships can be cleaned for SO_2 in a scrubber where SO_2 is washed out of the flue gas using seawater. Inside the scrubber, SO_2 is transformed into harmless sulphate (SO_4^{2-}) that can be discharged with the scrubber water at sea. However, the scrubber water also contains several toxic tar compounds. Hence, it cannot be discharged near coastal areas. Here it is stored in tanks and recirculated (with added sodium hydroxide). According to Alfa Laval Aalborg, a scrubber removes more than 95% of SO_2 and usually 50-60% of the particles in the flue gas. DFDS is seeing the same results from their scrubbers in operation. During testing, some scrubbers have shown removal rates of 70-80% of particles (*Venturi scrubber*). It has, however, not been documented whether scrubbers primarily remove inorganic particles or to what extent they also remove soot particles. A scrubber can thus achieve the same SO_2 reduction as low-sulphur fuel oil and meet the regulations inside SECAs as well as the 2020 global sulphur regulation. Using a scrub-



SO_2 and particle emissions can be significantly reduced in a scrubber.

Source: Alfa Laval Aalborg



The NO_X-emission can be minimized by SCR technology.

Source: DANSK TEKNOLOGI

ber can thereby be an alternative to low-sulphur fuels. The potential of scrubber technology will depend on the fuel prices. DFDS and Royal Arctic Line have both chosen to implement scrubber technology, whereas Maersk Line has chosen to use low-sulphur fuels.

For 4-stroke engines selective catalytic reduction (SCR) is one of the most promising technologies for the removal of NO_X. In SCR systems, a precise amount of urea is automatically added to the flue gas. Ammonia (NH_3) is released from urea at high temperatures and reacts with NO_X in the flue gas, converting NO_X and ammonia to harmless free nitrogen (N_2) and water vapour. SCR systems for ships can remove more than 90% of NO_X in the flue gas at high temperatures (above 300 degrees Celcius). Is the temperature lower, ammonia can be added as a pure gas, thus maintaining high efficiency down to 180 degrees Celcius. Some studies also show particle removal when using SCR systems. Finally, SCR systems can reduce noise significantly. SCR systems have been successfully used on both 2-stroke and 4-stroke engines.

Particles can be removed from the flue gas by using particulate filters - the same technology as is widely used in diesel cars. Particles are removed by a physical filtration process in a closed particulate filter. Through electrical regeneration (controlled particle combustion inside the filter) particles are transformed to CO_2 and water vapour. Low-sulphur content in the fuel oil reduces ash formation and enhances the filtration process. Full scale testing with particulate filters on the Ærø ferry carried out by Dinex A/S has shown 90% particle removal for both fine and ultrafine particles. Finally, particles can be removed very efficiently in a dry scrubber. CCR Denmark has demonstrated through full scale testing a removal of ultrafine particles of 99.8% in a dry scrubber.

Particles can be efficiently removed by particulate filters.

Source: Dinex A/S.

Combining technical solutions
Many of the technical solutions can be combined on ships as done on newer trucks and busses to comply with environmental regulation in the developed part of the world where heavy duty vehicles use both desulphurized fuels (max. 0.001% sulphur), EGR combined with SCR and closed particticulate filters. By combining solutions the pollution from shipping can be significantly reduced (table 6).

Table 6: Reductions by combining solutions compared to a traditional container ship (in percent)

	LNG	**LNG + WHR**	**LNG + WHR + EGR**
CO_2 reduction	20-25	30	30
SO_2 reduction	> 90	> 95	> 95
NO_x reduction	> 20	> 25	> 90
Particle reduction	> 40	> 45	> 60

LNG: Liquid natural gas. **WHR:** Waste heat recovery. **EGR:** Exhaust gas recirculation.

REGULATION

As previously mentioned, global environmental regulation for shipping is decided by the IMO.

Sulphur regulation

Table 7 shows the IMO regulation on the sulphur content in ship fuels. As an alternative to low-sulphur fuels, ships can choose to remove SO_2 from the flue gas in a scrubber.

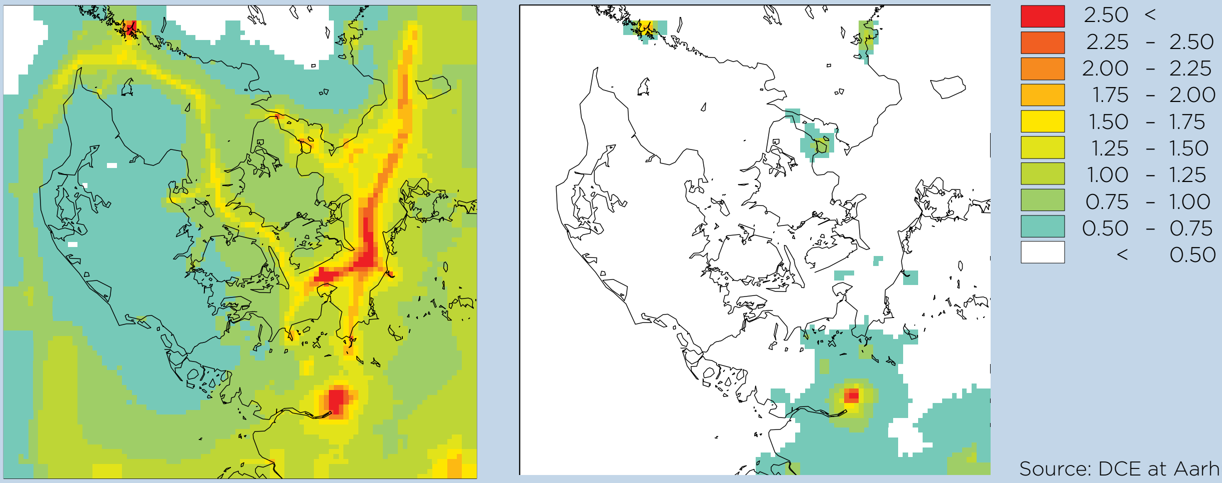
The seas around Denmark are SECA. Hence, sulphur emissions have been reduced by around 93% between 2006 and 2015. The reduction is percentagewise somewhat lower than the reduction of the sulphur content (96%) in the fuel as there has been a simultaneous increase in shipping activity. However, a reduction of sulphur emissions of more than 90% shows that SECAs are a success. It also highlights NO_x pollution from ships as the major remaining problem, now accounting for 95% of total health damage from ships in the North Sea and the Baltic Sea.

An estimation of SO_2 concentrations in the air in Denmark in 2007 and 2020 is given in figure 4. It clearly shows that shipping has a significant effect on SO_2 concentrations in 2007, whereas the pollution is almost invisible in 2020 despite increasing shipping activity between 2007 and 2020.

Table 7: Global regulation of the maximum sulphur content in ship fuels (percent)

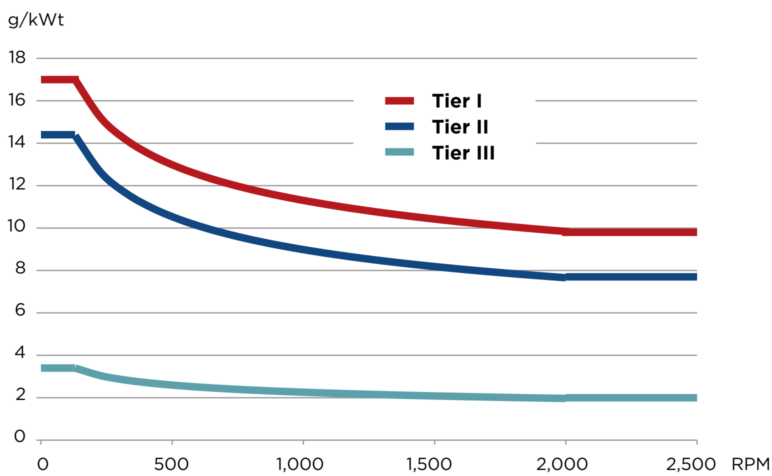
		2007	2010	2012	2015	2020
Sulphur content	**Non-SECA (World seas)**	4.5	-	3.5	-	0.5
	SECA	1.5	1	-	0.1	-

Figure 4: SO_2 concentrationen (µg/m³) in Denmark in 2007 and 2020



Source: DCE at Aarhus University.

Figure 5: Regulation of NO_X from shipping



Tier I: Ship engines (above 130 kW) installed on a ship built after 1st January 2000

Tier II: Ship engines (above 130 kW) installed on a ship built after 1st January 2011

Tier III: Ship engines (above 130 kW) installed on a ship built after the year the NECA came into force.

Source: International Maritime Organization

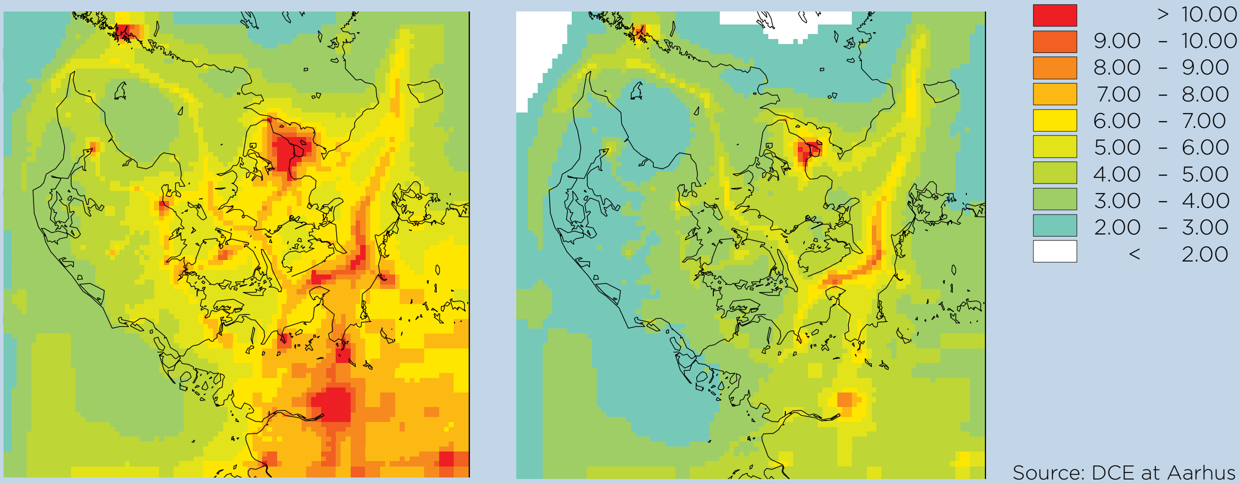
The estimated decline in sulphur concentrations (figure 4) is supported by Danish measuring stations. Following the tightening of the regulation inside SECAs in 2015, these now detect half the sulphur concentration on land. This decrease documents that air pollution from shipping is dispersed over land and has a significant influence on air quality and thereby on public health. In addition to the Northern European SECA in the Baltic Sea and the North Sea, two SECAs have been established in North America/US.

NO_X regulation

Figure 5 shows the global regulation of NO_X emissions from ships. In line with SECAs, NECAs have now been introduced. For 2-stroke engines, in addition to implementing EGR and SCR, NO_X reductions of 80% for Tier III can be achieved by using LNG in some engines.

Although NO_X causes most of total health damage (cf. table 4, page 11), the significant NO_X reductions (Tier III) only apply to new ships (built after the NECA came into force) and only inside the NECA. At present, NECAs is only established in North America/US. The current SECA in the North Sea and the Baltic Sea will be extended to a NECA from 2021, after which Tier III will apply to new ships in Danish seas. However, as soon as a ship leaves the NECA, it must only meet regulations of Tier II and can significantly reduce NO_X removal. Finally, ship engines built between 1990 and 2000 must be upgrated to Tier I but only if technology is available.

Figure 6: NO_2 concentrations (µg/m³) in Denmark in 2007 and 2020



Source: DCE at Aarhus University.

It should be noted that it is the age of the ship and the engine's power that determines how much the ship can pollute with NO_x. Old ships and smaller ships can thus pollute more than new and large ships. This gives an incentive to maintain old small ships, which in general pollute much more than new large ships.

Estimations of NO_2 concentrations (indicator for the NO_x pollution) in Denmark in 2007 and 2020 are shown in figure 6. During this period, a small increase in NO_x emissions in the seas around Denmark is expected due to increased shipping activity. Yet, the concentration of NO_2 will decrease significantly thanks to a substantial decrease in emissions from land-based emission sources due to further restrictions by EU regulation. Nevertheless, the NO_x regulation of shipping has a positive effect, since ships' NO_x emissions without regulation would have increased by 10-15% from 2007 to 2020. However, the increase will be kept at 2.5% due to the regulation. By 2040, the upcoming NECA in the North Sea and the Baltic Sea is expected to have reduced NO_x emissions in the NECA by about 66% compared to baseline without a NECA.

Finally, particle pollution is significantly reduced because of the sulphur and NO_x regulation. This applies to both the particle pollution formed directly in the engine (including black carbon) and the secondary particles formed through atmospheric reactions. However, no direct regulation of particle pollution has been decided – neither in the climate-sensitive arctic areas nor in metropolitan ports.

CO_2 regulation

The IMO regulates CO_2 emissions from new ships through the Energy Efficiency Design Index (EEDI), which is mandatory for all new ships built after January 1, 2013. EEDI promotes more energy efficient ships by requiring increased energy efficiency for different ship types and sizes compared to a specified reference level. It is measured in grams of CO_2 per transport work (capacity mile) and calculated from several parameters: ship type and design, fuel, engine type and size, propellers, etc. By further tightening the regulation every five years, new ships will continue to be more and more energy efficient. The regulations only focus on the performance of ships and not on the technologies used to fulfil the regulations. This allows ship designers and ship builders to freely choose the most efficient solutions and motivates to develop even better technologies. More than 85% of CO_2 emissions from shipping originate from ship types covered by EEDI. However, as the lifespan of a ship is typically 25-30 years, EEDI will first influence CO_2 emissions in the long term. Table 8 lists the EEDI regulations for different types of ships.

The IMO has also adopted the Ship Energy Efficiency Management Plan (SEEMP) as an operational tool, reducing the fuel consumption of ships and thereby CO_2 emissions. SEEMP can be used for both new and existing ships and is based on *best practice* in relation to energy efficient operation. This can be combined with Energy Efficiency Operational Indicator (EEOI), which is a monitoring tool that allows monitoring fuel efficiency during various operational changes. The IMO has developed teaching modules in SEEMP.

By 2050, it is expected that EEDI/SEEMP have cut up to approximately 1,000 million tonnes (30-40%) of CO_2 emissions from shipping, compared to a baseline without CO_2 reductions. In addition to EEDI/SEEMP, the IMO has initiated a project on further CO_2 reductions from shipping, which will lead to a whole new climate strategy framework in 2023 that will allocate CO_2 reductions in the short, medium and long terms. In addition to CO_2 reductions, fuel savings (burning less fuel) will, all things being equal, reduce air pollution with SO_2, NO_x and particles.

Table 8: EEDI regulations (reductions in percent) for different ship types built in different years

	Size (Dwt)	**Reduction 2015-19**	**Reduction 2020-24**	**Reduction 2025 – ...**
Bulk carriers	> 20,000 10-20,000	10 0-10 [1]	20 0-20 [1]	30 0-30 [1]
Gas tankers	> 10,000 2-10,000	10 0-10 [1]	20 0-20 [1]	30 0-30 [1]
Tankers	> 20,000 4-20,000	10 0-10 [1]	20 0-20 [1]	30 0-30 [1]
Container ships	> 15,000 10-15,000	10 0-10 [1]	20 0-20 [1]	30 0-30 [1]
General cargo ships	> 15,000 3-15,000	10 0-10 [1]	15 0-15 [1]	30 0-30 [1]
Refrigerated cargo carriers	> 5,000 3-5,000	10 0-10 [1]	15 0-15 [1]	30 0-30 [1]
Combination carriers	> 20,000 4-20,000	10 0-10 [1]	20 0-20 [1]	30 0-30 [1]

Dwt: Dead weight tonnage.

1) The reduction factor is linear in the interval (highest for large ships and lowest for small).

Table 9: Estimated emission of pollution from shipping in the seas around Denmark.

	CO_2	SO_2	NO_X	Fine particles
2011 (tonnes)	7,850,000	41,000	173,250	4,000
2020 (tonnes)	9,250,000	6,000	177,600	2,650
Changes in %	+ 18	-85	+2,5	-34

Source: DCE at Aarhus University.

Estimated emissions of CO_2, SO_2, NO_X and fine particles from shipping in seas around Denmark in 2011 and 2020 are shown in table 9.

CO_2 and NO_X emissions show a net increase between 2011 and 2020 due to an increase in shipping activity and a weak regulation of these pollutants. Hence, CO_2 and NO_X pollution from shipping will continue to be the most urgent challenge both inside and outside NECAs. The highest reduction is seen for sulphur, resulting directly in reduced particle emissions. Outside SECAs, the global sulphur regulation from 2020 will result in a reduction in particle emissions as well. However, emissions of soot particles (black carbon) will continue to be a problem in arctic areas and metropolitan port areas. Recent studies indicate that the fuel oil quality (aromatic content) is a crucial parameter to black carbon formation and emissions.

Although the IMO regulation is a major step in the right direction, shipping is still subject to much less strict regulation than land-based transport. Fuel oil used in SECAs contains 100 times more sulphur than road diesel. Even new ships in NECAs (Tier III) can emit 5-7 times more NO_X per kWh engine power compared to new trucks. Additionally, they emit more than 50 times as many particles. Hence, even the strictest IMO regulation in SECAs and NECAs does not change shipping to the *green* transport of the future. As a result, health and nature damage caused by air pollution from shipping will for many years be a major economic burden for society; primarily due to a weak NO_X regulation. Considering the climate, there is need for action as the existing regulation does not reduce CO_2 emissions from shipping to a level in line with the goal of the Paris agreement: To keep the anthropogenic global warming at a level that avoids dangerous and irreversible climate change. Thus, there is an urgent need for stricter regulation of pollution from shipping – especially NO_X and CO_2 – before the sector becomes the *green* transport of the future in an increasingly globalised world.

ENFORCEMENT

International environmental regulation of shipping is needed to gain major socio-economic benefits from reduced air pollution. Regulation is, however, not sufficient in an international industry, where circumvention and corruption is widespread. To avoid systematic violations of the regulation, enforcing the regulation will be just as important as the regulation itself to achieve the full environmental benefits. The economic incentive to circumvent the regulation is considerable while enforcement is modest; control and fines are symbolic compared to the economic savings from circumvention. Thus, there is a real risk that shipowners violating the regulation will outmatch compliant shipowners fulfilling the regulation and thereby earn money on harming society. Finally, systematic violations must be avoided to allow compliance costs (e.g. extra fuel costs) to be transferred from shipowners to cargo owners and further on to end consumers who get the benefits of less mortality and morbidity. Efficient enforcement prevents violations by making it more expensive to circumvent the regulation than to comply with the regulation. This requires the right balance between control and sanctioning for circumvention. If the risk of being caught violating the regulation is low, the economic sanctions must, of course, be high to prevent non-compliance. However, the IMO regulation only focuses on environmental regulation. IMO entrusts the enforcement to the flag states, which have a very different priority of regulation.

The world's largest shipping companies have now joined forces in Trident Alliance only to achieve enforcement of the sulphur regulation

The enforcement of the sulphur regulation in SECAs and on a global level from 2020 has been the object of intense discussions. In SECAs, savings of around USD 165,000 per ship (English Channel to Gdansk and back) can be attained by using traditional HFO instead of the required more expensive low-sulphur fuel oil. Hence, ships violating the regulation can make higher profit and offer lower prices than compliant shipowners. NO_x regulations in NECA (Tier III) will face similar challenges.

The Danish Ecological Council has organised several large conferences in Copenhagen and Brussels on enforcement in close cooperation with Danish Shipping and other key stakeholders.

North European SECA

To meet the challenges associated with enforcement, the EU has passed a directive establishing a procedure for port state control in the EU. Member States perform the port state control and must inspect 10% of all port calls to control logbooks, fuel oil receipts, etc. In addition, fuel samples for sulphur analysis must be carried out in 4% of all port calls. However, fines for violations are based on national decision (non-EU competence). Nonetheless, according to the EU directive fines must be high enough to prevent systematic violations. Hence, if the risk of getting caught in the SECA is 4-10% while the saving is USD 165,000, the fines should be USD 1.65-4.13 million just to break even. Higher fines are needed to make violations unattractive. However, fines are typically 50-100 times lower (USD 0.03-0.06 million). Thus, from an economic viewpoint, the benefits of non-compliance are 50-100 times greater than being in compliance, if inspections are only performed randomly. However, focused inspections through international cooperation can reduce the benefits of non-compliance.

To support port state control, Denmark has installed sulphur measuring equipment under the large bridges, and authorities conduct controls at sea using helicopters measuring sulphur directly in the ships' flue gas. Based on the ratio of CO_2 and SO_2 in the flue gas, the sulphur content of the fuel oil can be calculated. If these measurements indicate non-compliance, authorities are immediately contacted at the ship's next port. There, a sulphur sample of the fuel oil is taken, which can be used as evidence in court. Finally, the authorities have just taken an initiative to create a public register that displays shipping companies (name and shame) who are caught circumventing the regulation.

Since the regulations inside SECAs were tightened in 2015, Danish authorities have reported about 20 cases of violations to the police. During the same period, there have been approximately 300,000 ship passages in the seas around Denmark. According to model calculations, the measured sulphur reduction indicates that more than 95% of the ships inside the SECA fulfil the sulphur regulation.

The 9,865 inspections that were carried out in the EU's SECA until spring 2017 showed that 92.5% of the ships complied with the regulations. Of the 7.5% that did not meet the regulations, several of the violations were of administrative character (insufficient logging, missing fuel receipts, etc.), and not non-compliant fuel.

The small, Danish entrepreneurial company *Explicit* is specialised in monitoring sulphur emissions from ships through measurements from helicopters and drones.

Global 2020 regulations

The IMO has just taken a step towards prohibiting ships without certified scrubbers to carry fuel with above 0.5% sulphur in the fuel tanks when the new global regulation of sulphur enters into force in 2020. If this decision becomes reality, it will be an important element for enforcement of the 2020 regulation. Efficient enforcement of the 2020 regulation will reduce the benefit of non-compliance in SECAs as well, since the price difference between a fuel with 0.5% sulphur and one with 0.1% sulphur, all things being equal, will be smaller (compared to the price difference between fuel with 2.5% sulphur and 0.1% sulphur), which implies less profit from non-compliance in SECAs.

NO_x regulations inside NECAs

It is expected that the NO_x regulations (Tier III) must be checked by performing standard tests at artificial test facilities and through log files from the systems while operating. This gives a potential for systematic violations, resulting in real-life NO_x reductions being significantly below 80%. For diesel cars, it is well-known that emissions of NO_x are 3-5 times higher on the road compared to the type-approval emissions. In addition, the SCR system of trucks can easily be chip tuned so that the engine system thinks that the SCR is working even though it is off and there is no NO_x reduction. Shipping may face similar challenges, if no efficient NO_x control inside NECAs is introduced.

Effective enforcement

An obvious possibility to achieve effective control is to install sealed online SO_2 and CO_2 sensors in the ships' stack (similar systems are mandatory for ships with installed scrubbers) and make the results available through the AIS system (Automatic Identification System). This ensures constant monitoring of sulphur emissions from the ship, which reveals any non-compliance both inside and outside SECA. Legally, it is not realistic that the IMO will decide this. However, if key regional units (EU, US, Canada, etc.) decide that only ships with such equipment installed will gain port access, it will matter significantly; likewise, an increasing support for such a regulation from other important shipping regions, e.g. China, ultimately, can make the regulation practically global. As an alternative, port state control can be intensified and combined with several national measures such as helicopters and drones with measuring equipment. However, this is expensive and can only be done regionally in coastal areas. Finally, discussions on monitoring through *big-data*, where model estimations based on fuel receipts, ship data and sail routes can tell whether a ship at all times has been able to use compliant fuel, are ongoing.

The NO_x regulation (Tier III) inside NECAs is more difficult to enforce as it necessitates constant monitoring of the EGR and SCR equipment to ensure that these fulfil the desired NO_x reductions, which are defined per kWh engine power (cf. figure 5 above). However, it is also possible to continuously measure NO_x emissions from the stack, and these measurements can be combined with ship engine data and the CO_2 content in the flue gas. Thereby, an estimation of the NO_x emissions per kWh can be made, which can be made available through the AIS system. In this way, the ship can be monitored to see if the NO_x regulation (Tier III) is complied with during operation at sea.

In addition, sanctioning may be harmonised within the EU using detention sanctions, where ships violating the regulations are detained for e.g. 15 days in EU ports. On top of extra expenses for port fees, etc., the ship insurance does not cover delay costs when the cargo is delayed due to violations of international sulphur and NO_x regulations.

Finally, shipping companies who are violating the regulation may be displayed publically in large, international registers. Hopefully, insurance companies will deny insuring these shipowners, large companies will avoid using them for transportation, large banks will not authorise loans for them, pension funds will not invest in such shipping companies, ports will deny access for their ships, etc.

FURTHER REGULATION

As mentioned above, shipping (and air pollution from shipping) is traditionally regulated by the IMO, governing the regulation globally. This solves several challenges such as reflagging of ships to flag states with less strict environmental legislation as well as legal challenges connected to regulation of pollution in international seas. The challenge is, however, that the decision-making process within the IMO is slow and that the decisions are not always environmentally ambitious, since the many stakeholders within the IMO have very different opinions when it comes to the environment and climate. From a socio-economic point of view, and to fulfil the Paris agreement for shipping, there is a need for further environmental regulation within the IMO. In addition, market-based regulation of shipping is an overlooked possibility. Finally, regional regulation (or threats of it), e.g. from the EU, often stimulates more ambitious decisions in the IMO. Below, three options for further regulation are discussed, holding the potential to transform shipping to the *green* transport of the future.

1) Further IMO regulation
2) Marked-based regulation
3) Regional regulation

Further IMO Regulation
The existing IMO regulation reduces sulphur emissions by 80-90%. In the short term, no further regulation of SO_2 emissions from shipping (except for the implementation of more SECAs) should be expected. Instead, enforcement inside and outside SECAs must be prioritised to get the full benefits of the regulation. In the long-term perspective, however, it will be necessary to further reduce sulphur emissions from shipping. This may happen by using alternative fuels and/or by switching to road diesel, since road diesel will become cheaper gradually with the phase-out of diesel cars, which will result in an excess supply of road diesel.

In relation to NO_x, the Tier (III) regulations inside NECAs should be implemented globally; initially for new ships and shortly thereafter for existing ships (e.g. by retrofitting SCR systems). NO_x continues to be the greatest health cost caused by shipping, both inside and outside NECAs. Much stricter global NO_x regulation will ensure optimal regulation from a socio-economic point of view. Until then, as many NECAs as possible should be established.

Negotiations at the IMO are often slow

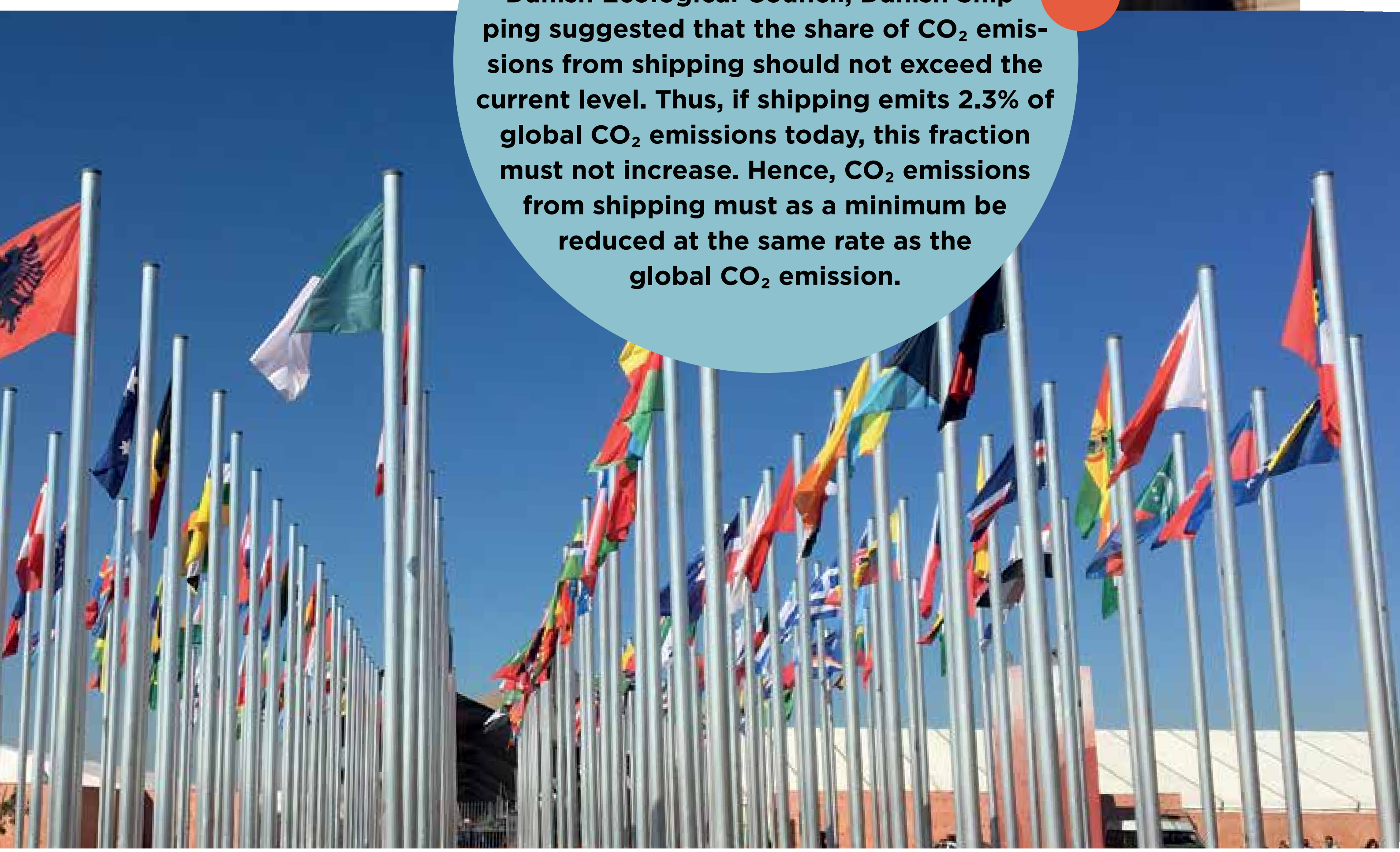
Regulation of particle emissions from shipping should include a requirement for particulate filters (or similar technologies), if ships operate in sensitive areas. This is especially relevant in the Arctic, where soot particles (black carbon) from shipping to a large extent are deposited on the ice, contributing to ice melting and thereby to global warming. Further, a significant increase in shipping activity through the Arctic is foreseen as the sea ice melts and a shortcut opens through the Arctic. It is therefore highly urgent to implement such regulations. However, ports with residential and recreational areas, with significant pollution in the form of ultrafine soot particles from shipping, have a need for particle regulation as well. In the Arctic, an obvious first step is a ban on the use of HFO, which will reduce emissions of black carbon. Already, a similar HFO ban exists in the Antarctic. Such a ban will also enhance the use of particulate filters and reduce the consequences of oil spills in the sensitive arctic ecosystems, where it is almost impossible to clean up, and oil pollution decomposes very slowly. A ban on the use of HFO in the Arctic is currently discussed at highest levels in the IMO; thanks to the work of the *Clean Arctic Alliance* funded by the *European Climate Foundation* through a grant from *The Dutch Postcode Lottery*. Danish Shipping and many flag states support the basic idea of this initiative.

Even with the existing regulation, CO_2 emissions from shipping are expected to significantly increase by 2050 due to increased shipping. This goes against the Paris agreement. An obvious option is to tighten the IMO's existing EEDI regulations for 2020 and 2025 (cf. table 8, page 24) as soon as possible and to introduce ambitious EEDI regulations for 2030 and onwards. A CE Delft study shows that a substantial fraction of the ships that started operating back in 2014/15 can easily meet the 2020 regulations. The most efficient ships from 2014/15 can even meet the 2025 regulations. This strongly indicates that the EEDI requirements have already been outdated by technological progress. The EEDI regulation must be based on the most efficient ships and the expected progress to achieve the desired climate goal. Based on the CE Delft study, it seems obvious to at least raise the EEDI regulations for most ship types to 35/50% by 2020/25 (rather than continuing with the current EEDI regulations of 20/30% by 2020/25). As rapid technological development is expected, the 2030 regulation could be set at 75%, if technology/design is documented available by 2028.

In addition to a stricter EEDI regulation, a global tax on fuel oil could be introduced for ships (highest on HFO). Such taxation would in general motivate fuel savings and promote the most energy efficient ships, while at the same time introducing an even greater developmental pressure on ship designers, ship builders and ship operators to work towards higher energy efficiency. The yield from taxation could be used for development of cleaner shipping and environmental improvements in developing countries (otherwise it would be difficult to gain support for the proposal at the IMO from these countries). The tax may be raised by 2050, if CO_2 emissions are not reduced sufficiently in relation to the Paris agreement.

In the short term, the most efficient way to achieve CO_2 reductions is to reduce speed. It is therefore obvious to introduce a global speed limit for ships; just as there are existing speed limits for trucks. Ship speed is measured in the AIS and will therefore be easy to control. Furthermore, sanctions must be introduced to ensure that ships comply with the speed limit. This will be the most efficient method to ensure a swift CO_2 reduction from shipping, thereby buying time until the more long-term actions take effect. The speed limit should be differentiated so that CO_2 neutral ships can sail at their desired speed, while energy efficient ships can sail at a higher speed than inefficient ships. This will help accelerate the development of CO_2 neutral ships. Finally, reduced speed will increase the need for ships, and ensure better utilisation of the capacity of ships, to maintain the transport capacity. This will reduce overcapacity and make shipping a much more profitable business.

At a high-level kick-off event for delegations during COP22 in Marrakech in 2016 organised by the Danish Ecological Council, Danish Shipping suggested that the share of CO_2 emissions from shipping should not exceed the current level. Thus, if shipping emits 2.3% of global CO_2 emissions today, this fraction must not increase. Hence, CO_2 emissions from shipping must as a minimum be reduced at the same rate as the global CO_2 emission.



Market-based regulation

The first step towards market-based regulation is to create market transparency, i.e. information on pollution from different ships. This creates a market signal allowing cargo owners, banks and professional investors to select the least polluting ships. The market signal must be understandable and the ranking method must be based on transparent conditions.

Environmental labelling of ships from A to E, as it is known from other sectors, is an effective market signal. The labelling should be based on reductions relative to a well-defined baseline (such as it is done with the EEDI), e.g. based on reductions compared to pollution from a standard ship on the same route in 2013-14. The baseline and reductions must be documented by an independent and recognised audit. The IMO may select organisations that issue labels based on the audit. Table 10 lists proposals for reductions (compared to baseline) needed for different labels.

The minimum regulation that must be fulfilled to obtain label E is a basic reduction compared to the baseline. However, this reduction is achieved through the existing sulphur regulation combined with minor operational changes and simple technical solutions. To attain a D label, more than just minor changes must be made. Good, new container ships with EGR, LNG ships using *slow steaming*, and good newer ships with simple SCR plus other operational measures, will automatically achieve a D label.

Better labelling requires both good, new ships and/or the installation of a wide range of operational and technical solutions (described above) combined with new types of fuels. B label may be obtained by switching to LBG, while electric powered ships within the EU can be given an A label, since CO_2 emissions from power generation are regulated by a fixed number of emission allowances (emissions of SO_2, NO_x and particles from the power plants are regulated by emission allowances as well). Thereby in principle, a ship becomes pollution neutral when using electricity, as the number of CO_2 (SO_2, NO_x and particles) emission allowances do not increase.

Table 10: Reductions for environmental labelling in percent compared to the baseline.

	A	B	C	D	E
CO_2	95	75	50	40	30
SO_2	95	95	90	80	80
NO_x	95	80	80	50	20
Fine particles	95	80	50	30	30

The Norwegian government pension fund, which invests more than USD 995 billion, has banned investments in four shipping companies after discovering that they left their ships for scrapping under questionable environmental conditions in Bangladesh and Pakistan. If large pension funds, such as this one, decide only to invest in shipping companies with labelled ships from 2025, the labelling would have a swift offset.

The labelling should be voluntary just like the FSC label and Fairtrade. Through the labelling, large global cargo owners, banks and professional investors can integrate pollution from shipping in their environmental policies (CSR goals). For instance, a cargo owner can choose to use at least 40% C labelled, 30% D labelled and 30% E labelled ships from 2025; similarly, banks and professional investors (e.g. pension funds) could decide to only lend money to and invest in shipping companies that, by 2025, have as a minimum label E ships. Investment rules could then be tightened year after year.

The labelling enables companies' green accounting to include a quantitative overview of shipping activities categorised by labelling. This makes the pollution from shipping visible, thus enabling public procurement officers and large, responsible companies to dictate environmental regulations for their suppliers' shipping transport. Environmental NGOs can also push companies to request more and more ambitious labels for their shipping transport. Ultimately, consumers can through the media be made aware of the environmental shipping label used by companies, thereby visualising the pollution from shipping to the end user. Hence, the consumer can push companies even further towards more ambitious environmental labels for their ship transport.

As a result, some shipowners will see an economic potential in having labelled ships, as it becomes a condition for transporting certain cargo, getting certain loans approved and attracting certain investors. If more and more companies set environmental requirements for ship labels, more and more shipping companies will get labels for their ships. With an increasing demand for still more ambitious labels, shipowners will request still better ships that will emit still less pollution.

The largest technical challenge in the proposed labelling system is that, e.g., container ships often transport cargo for many different clients, which may demand different environmental labels. A need for flexibility may therefore be needed during a transition period. If 10% of the clients require label C, 20% require label D, 40% require label E and 30% have no requirements, the whole cargo can of course be transported by a ship with label C. Alternatively, the cargo could be transported so that the total pollution from the complete transport corresponds to 10% of the route being sailed with a label C ship, 20% of the route with a label D ship and 40% of the route with a label E ship. This will of course increase requirements for documentation and control during a transition period.

Regional regulation
Regional environmental regulation in important shipping regions has several times accelerated IMO decisions. As an example, the EU's decision to introduce a sulphur regulation of maximum 0.5% by 2020 (in EU seas outside the SECA) contributed to ensuring a global sulphur regulation of 0.5% by 2020 decided by the IMO. The EU has recently decided to integrate shipping in a regional CO_2 regulation by 2023, if the IMO does not provide an ambitious climate strategy prior to this.

Regional regulation introduces a progressive pressure on the development of the climate strategy in the IMO. It is stimulating a faster and more ambitious result than what would have been achieved without the EU regulation. Hence, regional regulation can both raise the bar and increase the probability of success in the IMO. Finally, the EU has decided on the so-called MRV (Monitoring, Reporting, Verification), which from 2018 requires that all ships calling at EU ports must report their CO_2 emissions. By expanding the MRV to include NO_x, SO_2 and fine particles, it can serve as a basis for a labelling system (cf. market-based regulation above).

In addition to the above labelling of ships (cf. page 32), regional areas (EU and US) could introduce port fees according to labels of ships: the better label, the lower port fees. By doing so, ships without a label would be charged very high port fees in the EU and/or the US, E labelled ships would be charged high fees, etc. This would ensure a direct economic incentive for ships to acquire a label and implement technical solutions and operational measures to attain the best possible label. Further, a decision dictating that all cruise ships and ferries in major EU ports must use land power (or efficient flue gas cleaning) by 2025, could be made. Regional regulation will require all ports within a larger area, e.g. the EU or the US, to coordinate. This could be done by making central decisions within the EU and/or the US on, e.g., harmonised minimum port fees for each ship label.

Consequences of regulations
As shipping is CO_2 effective compared to other modes of transport, it is important that regulation does not just encourage shifting cargo to trains and trucks. The regulation corresponding to the most ambitious labels (cf. table 10 page 32) will increase the price of ship transport, while no greater costs are connected to meeting the regulations for label C, D and E. Ship transport is, however, quite inexpensive compared to other modes of transport, thus a significant shift will hardly occur, even if regulation in the long term results in label B and A ships.

The actual transport costs for cargo transported by ship typically represent a few percent of the final product price. Therefore, possible price increases will hardly influence the demand, even when using the most ambitious environmental regulation. If, for instance, the transport costs are doubled for A labelled ships transporting wine from New Zealand to the EU, the price of the wine at the supermarket will increase with about 1%, which corresponds to roughly USD 0.08 per bottle. Such a price increase will not affect demand. For electronics coming from Asia, the relative price increase is much smaller. Only for low-cost products, such as wood pellets, coal, ore, etc., will the price increase be noticeable by implementing ambitious environmental regulation for shipping. However, trains and trucks will only to a very limited extent be competitive.

By ensuring international regulation or uniform regulation in larger regional entities, e.g. for ports in the EU/US, distortion of competition is avoided. Shipowners can thus pass on additional costs of cleaner shipping to cargo owners who will further pass on costs throughout the value chain until the consumer pays. Nevertheless, the price increase will be so small that the consumer will hardly notice the difference. In return, consumers gain longer and healthier lives and less nature damage.

Market-based regulation through labelling as well as regional regulation of shipping complements the IMO regulation and allows for faster pollution reductions. Stricter environmental regulation is needed because society, and not shipowners, pays for the damage caused by air pollution.

COMMERCIAL POTENTIALS

Denmark has a unique position when it comes to shipping and technical solutions for reduction of air pollution from shipping. Denmark is the home of the world's largest container company, the world's largest developer and supplier of ship engines as well as the world's leading clean-tech companies in the field of flue gas cleaning technologies. Furthermore, Denmark has developed one of the leading research and consultancy communities in terms of mapping and reduction of pollution from shipping. Globally, Denmark is recognised as a leader in both shipping and clean-tech.

Several Danish key stakeholders within shipping have joined forces in *Green ship of the future*, an innovation network that aims at developing emission free shipping. The efforts towards cleaner shipping are also strongly rooted within the authorities and the industry associations *Danish Shipping* and *Danish Maritime*, acting at the forefront of international negotiations on cleaner shipping.

Danish ships are in general larger and newer than the average world fleet. Thus, pollution from Danish ships is on average less than the world fleet per transported tonne of cargo. These unique circumstances, together with the many Danish environmental competencies, make further environmental regulation of shipping possible. Further regulation will at the same time promote a swifter scrapping of the oldest and most polluting ships, which will be replaced by new ships, many of which will be equipped with a Danish engine and environmental technology. Thereby, further environmental regulation will only improve the competitiveness of the Danish maritime sector and both uphold and secure the status of the country as a leading green maritime nation. The same will be the case for all other flag states being frontrunners on maritime environmental matters.

RECOMMENDATIONS

To transform shipping into the green transport of the future, it is necessary to reduce air pollution further in both the short and the long terms. This will require a tightening of existing regulation and a focused effort on the international, regional and national levels.

The International Maritime Organization should:

> Initiate actions to ensure efficient enforcement of the global sulphur regulation from 2020.
> Expand the Tier III regulation of NO_X to all new ships from 2025 and all ships from 2030.
> Ban HFO as a fuel and require flue gas cleaning for black carbon in the Arctic from 2025.
> Introduce a speed limit for ships globally from 2023 (limit depending on ships' CO_2 emissions).
> Decide that CO_2 emissions from ships must not exceed 2.5% of global emissions at any time.
> Raise EEDI requirements to 35/50% by 2020/25; and to 75% by 2030, if it is technically possible.
> Decide on a global MRV for ships' emissions of CO_2, SO_2, NO_X and fine particles from 2025.
> Introduce a tax on fuel from 2025 and invest the revenue in research and in developing countries.
> Develop a climate strategy that delivers CO_2 reductions in accordance with the Paris agreement.
> Decide that new ships by 2040 shall fulfil the same emission standards as trucks in the EU today.
> Initiate an ambitious and standardised labelling of ships based on CO_2, SO_2, NO_X and particles.
> Promote research and development towards cleaner shipping and share the knowledge globally.

Regional entities (EU, USA, Asia, etc.) should:

> Ensure efficient enforcement (control and sanctioning) of global and regional regulations.
> Introduce more SECAs and NECAs and share experience from enforcement with other regions.
> Exclude all shipping companies violating sulphur/NO_X regulations from regional ports.
> Devise a ship label system and introduce high port fees for ships with poor environmental labels.
> Recommend international companies to set clear CSR goals in relation to environmental labels.
> Require that cruise ships and ferries in all large ports use land power by 2025.
> Introduce a MRV system for CO_2, SO_2, NO_X and fine particles for ships by 2025.
> Introduce ambitious regional regulation that motivates the IMO to introduce similar global regulation.
> Promote research and development towards cleaner shipping and share the knowledge globally.

National authorities should:

> Push for stricter environmental regulation both at the IMO and regionally (see above).
> Ensure efficient enforcement of regulations and share this national experience globally.
> Recommend large international companies to set clear CSR goals in relation to ship labels.
> Promote national solutions and examples of green shipping companies at the international level.
> Promote environmental regulations for ship transport in the green public procurement policy.

MORE INFORMATION

Websites

Danish Ecological Council: www.ecocouncil.dk/en/front-page
Danish Shipping: www.danishshipping.dk/en
Clean Arctic Alliance: www.hfofreearctic.org
Green Ship of the Future: www.greenship.org
ICCT: www.theicct.org/marine
IMO: www.imo.org/en/OurWork/Environment/PollutionPrevention/Pages/Default.aspx
Transport & Environment: www.transportenvironment.org/what-we-do/shipping

Key publications

NO_x controls for shipping in EU Seas:
https://www.transportenvironment.org/sites/te/files/publications/2016_Consultant_report_shipping_NOx_abatement.pdf

Cost-benefit analysis of NOX control for ships in the The Baltic Sea and the North Sea:
www.ivl.se/download/18.3016a17415acdd0b1f4961/1493194706323/C228.pdf

Prevalence of heavy fuel oil and black carbon in Arctic shipping in 2015 and 2025:
www.theicct.org/sites/default/files/publications/HFO-Arctic_ICCT_Report_01052017_vF.pdf

Nordic Action for a Transformation to Low-carbon Shipping:
http://norden.diva-portal.org/smash/get/diva2:1111495/FULLTEXT01.pdf

CO_2 Emissions from International Shipping:
https://www.danishshipping.dk/en/policy/klimapolitik/klima/download/Basic_Model_Linkarea_Link/981/co2-study-appendix-2-technology-assumptions.pdf

Readily Achievable EEDI Regulations for 2020:
https://www.cedelft.eu/en/publications/download/2281

GLOSSARY

AIS: Automatic Identification System
CO_2: Carbon dioxide
DCE: Danish Centre For Environment And Energy
Dwt: Dead Weight tonnage
EEDI: Energy Efficiency Design Index
EEOI: Energy Efficiency Operational Indicator
EGR: Exhaust Gas Recirculation
GWP: Global warming potential
HFO: Heavy Fuel Oil
UN: United Nations
IMO: International Maritime Organization
LBG: Liquid Bio Gas
LNG: Liquefied Natural Gas
MRV: Monitoring, Reporting and Verification
NECA: NO_x Emission Control Area
NO_x: Nitrogen oxides
$PM_{0.1}$: Ultrafine particles
$PM_{2.5}$: Fine particles
SCR: Selective Catalytic Reduction
SECA: Sulphur Emission Control Area
SEEMP: Ship Energy Efficiency Management Plan
SO_2: Sulphur dioxide
UNFCCC: United Nations Framework Convention on Climate Change
USD: United States Dollars
WHR: Waste Heat Recovery
YOLL: Years of lost living

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CLEANER SHIPPING

About 90% of global cargo is transported by ships; shipping is thereby a key platform of increasing global trade. However, the high transport share and the weak environmental regulation of the sector result in a significant contribution to global warming and to air pollution with health damaging sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particles.

As air pollution from shipping can be transported over long distances, it significantly contributes to mortality, morbidity and nature damage on land. Every year, air pollution from shipping causes approximately 50,000 premature deaths in Europe and costs of more than USD 80 billion due to health damage. On top of this comes global warming and damage on nature, crops, buildings, etc.

The seas around Denmark have approximately 100,000 ship passages every year. As large container ships only sail 5-10 meters per litre of fuel, huge amounts of fuel oil are thus combusted in Danish seas near densely populated coastal areas with associated high air pollution. For NO_x, this pollution even exceeds the pollution from all Danish land-based sources.

The solution is to reduce air pollution from shipping on the local, regional and global levels and make shipping the *green* transport of the future. This requires both further environmental regulation of shipping and an efficient enforcement, which will ensure a level playing field allowing shipping companies to pass on the abatement costs to customers.

This booklet focuses on pollution with CO_2, SO_2, NO_x, fine and ultrafine particles from shipping, technical solutions, the existing environmental regulation and enforcement as well as commercial potentials through further environmental regulation of shipping. The purpose of the booklet is to inspire decision-makers and stakeholders to work focused on further regulation of air pollution from shipping to the benefit of public health, society, the climate and nature. In addition, the booklet is suitable for teaching natural science and social science classes.

THE DANISH ECOLOGICAL COUNCIL