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Scrubber Technology: Bad News for the Marine Environment

Ida-Maja Hassellöv

1 Introduction

In the late 1990s Corbett and Fischbeck concluded that international shipping is an important source of emissions of sulphur (and nitrogen) oxides, at local to global scale.¹ These findings supported the sense of urgency regarding the adoption by the International Maritime Organization (IMO) of a new Annex VI to MARPOL on Prevention of Air Pollution from Ships.² When entering into force in 2005, Annex VI was the first step towards implementation of gradually stricter limits on the maximum allowed sulphur content in marine fuels to reduce emissions of acidifying sulphur oxides to the atmosphere. In addition, the Baltic Sea became the first designated Sulphur Emission Control Area (SECA), to facilitate more progressive restrictions on maximum allowed sulphur content in marine fuels for ships operating in this sensitive sea area, starting at 1.5 percent sulphur content compared to the initial global cap of 4.5 percent. At that time, ships exclusively used heavy fuel oil (HFO), which is a residual product from the oil refinery process. During distillation, the sulphur content is enriched in the residual fractions and varies depending on the origin of crude oil from different geographic regions. The shipping industry plays a vital role as a market for the oil industry's residual products.

During the early discussions within the IMO on the necessity to limit the emissions of sulphur oxides from ships, the anticipated solution was that ships would switch to distilled fuels such as Marine Gas Oil (MGO) and there were concerns that the global fuel availability would be insufficient. However, at the 70th meeting of IMO's Marine Environment Protection Committee (MEPC) it was concluded, based on a report assessing fuel availability that there were no major barriers to implementing the planned global sulphur cap of 0.5 percent

1 James J Corbett and Paul Fischbeck, 'Emissions from ships' (1997) 278 Science 823.

2 IMO, *Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating thereto (MARPOL PROT 1997). Article 2. Addition of Annex VI, entitled Regulations for the prevention of Air Pollution from Ships, to the Convention.* (1997).

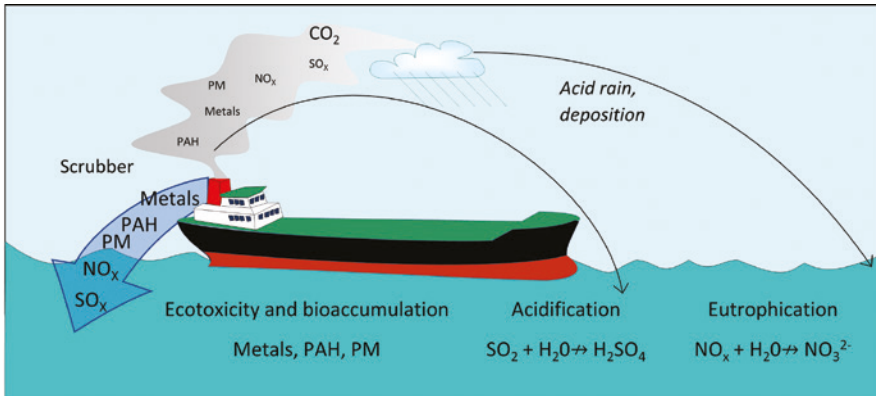


FIGURE 10.1 Redistribution of pollutants in ship exhausts through the use of scrubber technology. While the emissions to air and subsequent indirect deposition on the sea surface is reduced, the direct discharge to the sea is increased. The three major types of effects in the marine environment are ecotoxicity and bioaccumulation, acidification, and eutrophication.

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sulphur in marine fuels from January 1st, 2020.³ Yet, as MGO is more expensive than HFO, the cap may imply up to doubled fuel costs for some ship types. At the same time, there is a strong incentive to maintain the shipping industry's role as market for the oil industry's residual products. In the light of this situation, there has been a growing interest from shipowners to install an Exhaust Gas Cleaning System, also known as a scrubber, to comply with the stricter sulphur emission regulations instead of switching fuels (Figure 10.1).

Shipowners that have installed scrubbers, and the Exhaust Gas Cleaning Systems Association (EGCSA), choose to focus on the great capability of scrubbers to reduce atmospheric emissions of sulphur oxides. They also stress that the resulting end product will be sulphate, which is a natural component of seawater and although the scrubber discharge water is very acidic, seawater has a natural strong buffering capacity through its alkalinity.

So far, so good. However, the problem is that scrubbers, beside sulphur oxides, wash out many other types of pollutants and imply an increased load on an already stressed marine environment.⁴ This ought to be in conflict with

3 MEPC, *MEPC 70/INF.6. Assessment of fuel oil availability – final report. Submitted by Secretariat.* (2016).

4 Ida-Maja Hassellöv and others, *ICES Viewpoint background document: Impact from exhaust gas cleaning systems (scrubbers) on the marine environment (Ad hoc)* (2020); Benjamin S Halpern and others, 'Recent pace of change in human impact on the world's ocean' (2019) 9 *Scientific Reports* 11609.

the United Nations Convention on the Law of the Sea (UNCLOS),⁵ PART XII on protection and preservation of the marine environment, in particular Article 195 on the duty not to transfer damage or hazards or transform one type of pollution into another. According to this article, “[i]n taking measures to prevent, reduce and control pollution of the marine environment, States shall act so as not to transfer, directly or indirectly, damage or hazards from one area to another or transform one type of pollution into another”. Analogously, considering the UN Sustainable Development Goal 14 – Life below water and the motivation of the UN designation of 2021–2030 as the Decade of Ocean Science for Sustainable Development, aiming at improving the environmental status and ensure sustainable use of our seas and oceans, wide-scale use of scrubbers is a step in the wrong direction. The following section will describe in some more detail how different kinds of scrubbers function, and how they cause harmful discharges to the marine environment. (For a further discussion on risks connected to sustainable shipping, see the chapter by Rebelos in this volume).

2 Exhaust Gas Cleaning Systems (Scrubbers)

The general principle of a scrubber is that the exhausts are led through a fine spray of water, which provides efficient uptake capacity of sulphur oxides in the water (Figure 10.2).

According to DNV-GL Alternative Fuel Insight, the number of scrubbers currently in operation or in order is 4681,⁶ which can be compared to 312 in 2016, and 10 in 2011. Apparently many shipowners waited as long as possible before taking the decision to install a scrubber and according to SEB Macro Research: IMO2020 Report, the reasons not to install a scrubber are many: “*For shipowners a scrubber means capital expenditure, less free space on a ship, more maintenance, greater crew competence, higher fuel consumption and uncertain sludge disposal costs.*”⁷ In the end it is the price difference between residual HFO and low-sulphur fuels that determines whether a scrubber installation is beneficial for the shipowner, and prior to the COVID-19 pandemic, the

5 United Nations Convention on the Law of the Sea (Montego Bay, adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 397 (UNCLOS).

6 DNVGL, ‘Alternative Fuel Insight’. Scrubber Statistics. (2021) <<https://afi.dnvgl.com/Statistics>> accessed 10 March 2021.

7 Bjarne Schieldrop, *IMO 2020 Report New 2020 sulphur regulations for global shipping*. Macro & FICC Research, SEB (2018).

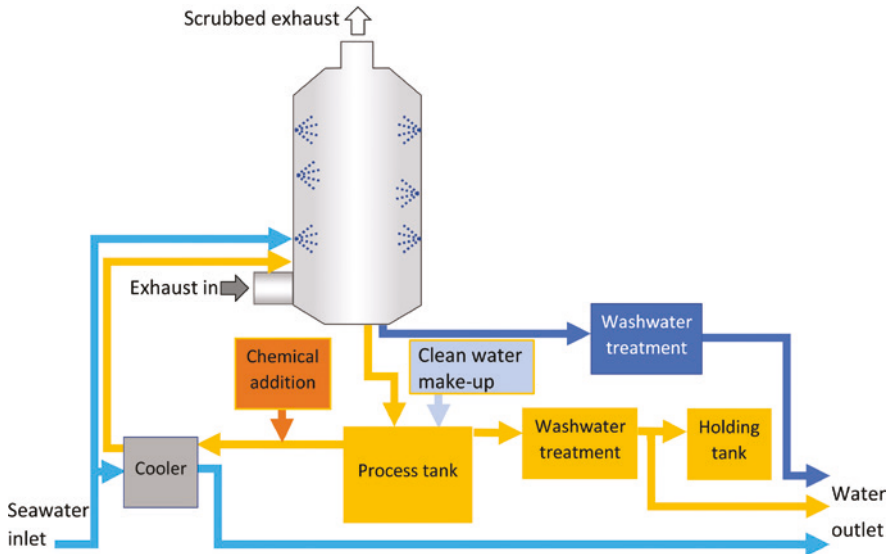


FIGURE 10.2 Simplified overview of a scrubber system in hybrid setup that can be run in open loop mode (light and dark blue lines) and closed loop mode (yellow lines). MODIFIED FROM EGCSA, 2012, WWW.EGCSA.COM/RESOURCES/TECHNICAL_GALLERY/

expected return of investment of a scrubber was 18 months.⁸ Yet, the external costs for the added environmental pressure on the marine environment is not considered in this trade-off. Nor is the working environment for the crew, who to a larger extent will be exposed to hazardous substances when operating a ship with a scrubber. Today more than 81 percent of the installed scrubbers are of open loop type, 1.5 percent are of closed loop and close to 17 percent are of hybrid type that can be operated either in closed loop or open loop mode.⁹

2.1 Open Loop Scrubbers

The simplest, and most common type of scrubber is the open loop, where large volumes of seawater (typically 500 cubic meters per hour for a medium sized ship of 12MW) are pumped onboard and then continuously discharged back to the sea after passing the scrubber. The open loop scrubber discharge water is very acidic (typically pH3, compared to natural pH8) and contains high concentrations of other pollutants, such as heavy metals and organic compounds

⁸ Personal communication, JB Fisher, Goldman Sachs Commodities Research, e-mail to author March 7, 2019.

⁹ DNVGL, 'Alternative Fuel Insight'.

like polycyclic aromatic hydrocarbons (PAHs).¹⁰ There are also reports on eutrophying effects from laboratory studies on phytoplankton,¹¹ indicating significant wash out of nitrogen species.

2.2 *Closed Loop Scrubbers*

Despite their name, closed loop scrubbers are rarely entirely closed systems; most often there is a bleed off, i.e. a small volume of washwater being discharged to the marine environment to allow for addition of base (typically sodium hydroxide) that is essential to maintain the sulfur oxide removal capacity in the scrubber process. World-wide there is only a handful of closed loop scrubbers where the ships leave all the produced sludge and scrubber water ashore for destruction instead of discharging the bleed off to the marine environment. Although the bleed off volumes are smaller (typically a few cubic meters per hour) compared to the discharge volumes from open loop scrubbers, the concentrations of pollutants, especially metals, are often much higher in the bleed off. This is due to recirculation of water in the closed loop system, which means the pollutants are enriched over time. The recirculation enables possibility to separate parts of the pollutants, especially PAHs that are often to large extent associated with particulate matter. To maintain the removal capacity of sulphur oxides, strong base (often sodium hydroxide) is added continuously to the water in the closed loop scrubber process. Thereby the local acidification of the marine environment is not as pronounced as following discharge of open loop scrubber water, but the load of other pollutants may still be significant.¹²

2.3 *Pollutant Load from Scrubbers*

To assess the pollutant load from scrubbers on the marine environment, the emission factors of the substances in scrubber discharge water can be calculated from the concentration of pollutants in the scrubber water, the produced discharge volumes during ship operations at different speed and engine load.¹³ This in turn can be combined with vessel activity data (AIS, Automatic Identification System) to produce a georeferenced dataset on the load of

10 Hassellöv and others (n 4).

11 Erik Ytreberg and others, 'Effects of scrubber washwater discharge on microplankton in the Baltic Sea' (2019) 145 *Marine Pollution Bulletin* 316.

12 Hassellöv and others (n 4).

13 J-P Jalkanen and others, 'Modeling of discharges from Baltic Sea shipping' (2021) *Ocean Science Discussions* 1,54.

pollutants from scrubbers entering the marine environment.¹⁴ Although these methods are well established, it is important to understand that the sampling and chemical analyses of scrubber discharge water is not trivial. Within the EU Horizon 2020-project EMERGE,¹⁵ Ytreberg and others have reviewed all publicly available chemical data on scrubber discharge water.¹⁶ Their conclusion, also supported by e.g. Teuchies and others,¹⁷ and Comer and others,¹⁸ is that the concentrations of pollutants in scrubber water are often very high, but also highly variable. The concentrations of metals, e.g. copper, zinc, chromium, and nickel, do not seem to originate from the fuel, but rather from lubricants, cathodic marine growth protection systems and leakage from the piping. Metal leaching from the piping can be expected to be accelerated due to the lowered pH of the scrubber water, implying that the use of scrubbers adds a new source of metal pollution from ships to the marine environment.

To put the load of pollutants from scrubbers in perspective, Hassellöv and others compared the emissions and discharge of metals and PAHs in the Baltic Sea from the ships operating with scrubbers, with other types of onboard-generated liquid waste streams containing these pollutants, i.e. bilge water from the engine room, black water (sewage) and grey water from sinks, laundry and galleys.¹⁹ In 2018 there were 99 ships operating with scrubbers in the Baltic Sea out of a total number of more than 8000 ships during the entire year. The load of metals and PAHs from the 99 scrubbers exceeded by factors in the range 10–100, the total load of these pollutants from the other liquid waste streams from the total fleet combined(!). The IMO has established guidelines regarding PAH content in scrubber discharge water, but these limits are so generous that in practice they can hardly be regarded as a restriction. Linders and others made a scoping calculation regarding the maximum allowed emissions

14 U Raudsepp and others, 'Shipborne nutrient dynamics and impact on the eutrophication in the Baltic Sea' (2019) 671 *Science of the Total Environment* 189.

15 EMERGE, *Evaluation, control and Mitigation of the Environmental impacts of shipping Emissions* (EU Horizon 2020 research and innovation programme under grant agreement No 874990. 2020).

16 Erik Ytreberg, Anna Lunde Hermansson and Ida-Maja Hassellöv, *Deliverable 2.1 – Database and analysis on waste stream pollutant concentrations, and emission factors. EMERGE: Evaluation, control and Mitigation of the Environmental impacts of shipping Emissions, funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 874990* (2020).

17 Johannes Teuchies and others, 'The impact of scrubber discharge on the water quality in estuaries and ports' (2020) 32 *Environmental Sciences Europe* 103.

18 Bryan Comer, Elise Georgeff and Liudmila Osipova, *Air emissions and water pollution discharges from ships with scrubbers*, ICCT Consulting Report, (2020).

19 Hassellöv and others (n 4).

of PAHs and concluded that if all ships emitted up to the allowed maximum concentration, the emissions of PAHs from shipping would by far exceed the emissions of PAHs from all other sources globally.²⁰ Restrictions of metal concentrations are not yet included in the guidelines. (On the regulation of ship source pollution on a regional scale, see further the chapter by Langlet in this volume).

3 Concerns for the Marine Environment and Policy Implications

Exhausts from ships without a scrubber will give rise to indirect input of pollutants to the marine environment through deposition on the sea surface (Figure 10.1). In comparison with the indirect deposition that is spread over a larger area depending on the current meteorological conditions, the use of a scrubber implies a more focused transfer of pollutants to the marine environment. Therefore it is important to use adequate spatiotemporal scales when modeling the effects in the marine environment. If annual averages are used to calculate the concentration of pollutants originating from scrubber water, the result can be misleading. Due to the natural seasonal stratification, especially in coastal areas during late summer months, discharges from intense ship traffic could induce temporarily higher pollutant concentrations locally. If living organisms are exposed to this temporary event of higher concentrations, it could potentially induce ecotoxicological effects that would not be expected if only assuming an average concentration based on the annual pollutant input to the annually mixed water volume.²¹

Besides the more efficient transfer of pollutants from a scrubber compared to indirect deposition, it is also important to understand that compared to use of a compliant distilled fuel, like MGO, Liquefied Natural Gas (LNG) or biofuels, the use of scrubbers implies an increased total load of pollutants to the marine environment. This is mainly due to the concentration of pollutants in the residual fuels, but also the new sources of e.g. metals leaching from piping due to the corrosive scrubber water that would otherwise not have reached the environment.

20 Jan Linders and others, *Exhaust Gas Cleaning Systems – A roadmap to risk assessment. Report of the GESAMP Task Team on exhaust gas cleaning systems. Submitted to PPR 7 as document PPR 7/INF.23* (2019).

21 Ida-Maja Hassellöv and others, 'Shipping contributes to ocean acidification' (2013) 40 *Geophysical Research Letters* 2731,2736.

3.1 *Ecotoxicological Effects of Scrubber Discharge Water*

Analogously with the challenges in chemical characterization of scrubber discharge water, the ecotoxicological testing of the water is also not straight forward.²² The difficulty of toxicity testing, and risk assessment of chemical mixtures is recognized at national and EU-level,²³ and scrubber discharge water is an excellent example of a chemical cocktail of acidifying and eutrophying substances, metals, and organic contaminants. There are still few scientific studies published in peer reviewed journals on the ecotoxicological effects of scrubber discharge water. However, the most well described effects are on marine copepods, small planktonic crustaceans that form an important base of the marine ecosystem. Exposure of copepods to 80–100 percent vol of scrubber discharge water induced mortality within minutes of exposure. Diverse chronic sub-lethal effects, such as reduced survival and feeding rates, delayed development, and molting, occurred at 1 percent vol of scrubber discharge water within days or weeks of exposure.²⁴ Interestingly, Koski and others did not find any correlation between individual substances in the scrubber discharge water and the severity of the response, implying that there were synergetic responses triggered by the mixture.²⁵

Studies on phytoplankton communities by Ytreberg and others showed a primary response in terms of increased growth following 13 days exposure to 10 percent vol scrubber discharge water that overshadowed any measurable response to the toxic substances.²⁶ Potential long-term effects of the toxic substances in the scrubber water cannot be ruled out but is challenging to assess as there will be enclosure effects of the experimental set up itself if running experiments for a period longer than roughly two weeks.

3.2 *Bans of Scrubber Water Discharge*

In accordance with Article 211 (3) UNCLOS, port States have full sovereignty over their ports.²⁷ Ports are thereby free to define and adopt more stringent

22 Hassellöv and others (n 4).

23 Christina Rudén, *Future chemical risk management. Accounting for combination effects and assessing chemicals in groups*, *SOU 2019:45*. (2019).

24 Marja Koski, Colin Stedmon and Stefan Trapp, 'Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod *Acartia tonsa*' (2017) 129 *Marine Environmental Research* 374.

25 *ibid.*

26 Ytreberg and others (n 11).

27 UNCLOS art 211 (3).

regulations, or even ban scrubber water discharge.²⁸ Beside the increasing number of ports taking action, e.g. Antwerp and Trelleborg, also regions, e.g. California and States, e.g. Germany and China, choose to ban discharge of open loop scrubber water.²⁹ In 2016 the European Commission (EC) replied to the members of the European Sustainable Shipping Forum's (ESSF) request on the views of the EC on the application provisions of the Sulphur Directive (SD)³⁰ and the Water Framework Directive (WFD),³¹ i.e. the EC's view on the use of scrubbers in European waters. In the reply it was stated that "*the use of scrubbers in EU waters, including the discharge of wash water, must not hamper any EU coastal State from complying with the binding obligations set in the WFD*".³² However, it was also noted that the rather local (river-basin specific) implementation of the WFD leaves it to national authorities to determine whether WFD obligations can be met also during discharge of scrubber water into the water bodies. Based on this reasoning, Germany has banned discharge of scrubber water not to jeopardize its obligations according to the WFD.

In the Baltic Sea there is consensus among the HELCOM countries that, with respect to eutrophication and hazardous substances, good environmental status is not met.³³ The brackish and shallow inland Baltic Sea has a large catchment area in relation to its volume and a long residence time due to limited water exchange through the narrow Danish straits. This, together with its northerly geographic location, implies that contaminants are slowly degraded and enriched in the bottom waters.³⁴ The Baltic Sea is also

28 Sonja Endres and others, 'A New Perspective at the Ship-Air-Sea-Interface: The Environmental Impacts of Exhaust Gas Scrubber Discharge' (2018) 5 *Frontiers in Marine Science*. 139.

29 DNVGL (n 10); Comer, Georgeff and Osipova (n 19).

30 EC, *Directive 2005/33/EC, the European Sulphur Content of Marine Fuels Directive (SCMFD)* (2005).

31 EC, *The EU Water Framework Directive – integrated river basin management for Europe. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Off. J. Eur. Union L 327*. (2000).

32 EC, *Note to the attention of the members of the European Sustainable Shipping Forum. Commission's views on the discharge of scrubber wash water and the updated table summarising the position of Member States on the acceptability of discharges of scrubber wash water – Agenda item 6.C ESSF of 26/1/2016. Directorate-General Environment. Directorate C – Quality of Life, Water & Air. Unit C.1 – Water and Unit C.3 – Air. Ref. Ares(2016)254855 – 18/01/2016*. (2016).

33 HELCOM, *State of the Baltic Sea – Second HELCOM holistic assessment 2011–2016. Baltic Sea Environment Proceedings 155*. (2018).

34 Claes Bernes and Martin Naylor, *Change beneath the surface: an in-depth look at Sweden's marine environment* (Swedish Environmental Protection Agency 2005).

prone to eutrophication. Based on this knowledge, there is also consensus in HELCOM that the pressure on the marine environment of the Baltic Sea needs to be reduced. In this marine environment perspective, the use of scrubbers in the Baltic Sea counteracts the strive for reduced environmental pressure, especially from shipping, in the region. Considering the development where an increasing number of States, regions and ports ban discharge of scrubber water, there is also a risk that an increased share of the global fleet of ships equipped with scrubbers are put in use in the regions where there is still no specific regulation of such discharges, which seems to be the case in the global modeling of scrubber washwater discharges by Osipova and others.³⁵

The increasing evidence of negative impacts on the marine environment,³⁶ and the modelling of global scrubber washwater discharge, where Sweden is on the top-ten list of States receiving the largest volumes of scrubber water in its economic zone,³⁷ could possibly encourage more Baltic ports to prohibit discharge of open-loop scrubber water. However, given the hydrographic characteristics of the Baltic Sea, described above, a continued wide scale use of scrubbers outside port areas will still pose a severe risk to this sensitive brackish environment. Use of closed-loop scrubbers with bleed-off implies less emissions of PAHs and metals to the sea compared to open-loop, yet the contaminant loads are significantly higher compared to the corresponding loads from ships using distilled fuels.³⁸ The only situation where scrubbers could be claimed to not deteriorate the marine environment is when closed-loop systems are truly closed, i.e. leaving all scrubber generated waste in port reception facilities for destruction. As mentioned above, there is a handful of such arrangements world-wide, and it is only feasible for ships in regular service on shorted distances, e.g. RoPax ferries between Trelleborg and Gedser-Rostock. To develop the port reception facilities of the ports in the Baltic Sea to enable ships to leave all their closed-loop waste in port would be an enormous project that would require extensive economic and environmental cost-benefit analysis to ensure that such investments can be justified.

35 Liudmila Osipova, Elise Georgeff and Bryan Comer, *Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit* ICCT Consulting Report, (2021).

36 Hassellöv and others (n 4).

37 Osipova, Georgeff and Comer, (n 35).

38 Anna Lunde Hermansson and others, 'Comparing emissions of polyaromatic hydrocarbons and metals from marine fuels and scrubbers' (2021) Transportation Research Part D: Transport and Environment 97 102912: <https://doi.org/10.1016/j.trd.2021.102912>.

4 Conflicting Perspectives

Current regulations to reduce emissions of acidifying sulphur oxides from shipping according to Annex VI of MARPOL, in the EU implemented through the Sulphur Directive, allow for alternative compliant technologies, instead of specifying individual types of compliant fuels. This results in optimization of compliance towards only one pollution aspect of marine fuels (sulphur oxides) but creates a loophole for increased pollution of the marine environment, e.g. through the use of scrubbers. If applying a more holistic perspective including potential effects on the marine environment, it can be argued that there is a conflict with UNCLOS Article 195 on the duty not to transfer damage or hazards or transform one type of pollution into another, and the EU member States' obligations under the EU WFD, and possibly the EU Marine Strategy Framework Directive,³⁹ especially Descriptors 8 (Contaminants), 5 (Eutrophication) and 7 (Alternations to hydrography).

These conflicting perspectives are further reinforced if also considering the transport policy objective of increasing the share of goods transported by ships, e.g. according to the EU White Paper on Transport.⁴⁰ An increased number of ships, or increased distances travelled by the existing fleet, will per se cause an increased pressure on the marine environment, which is especially pronounced for ships using scrubbers.⁴¹ Considering that the state of the marine environment is not satisfactory, there is an urgent need to include valuation of the impact on the marine environment following shipping activities. In Sweden this has recently been suggested by the Swedish Cross-Party Committee on Environmental Objectives to be developed and used in the continuous future assessments of the environmental impact of shipping carried out by the government agency Transport Analysis.⁴²

39 *Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy, Off. J. Eur. Union L164. (2008).*

40 EC, *White Paper. Roadmap to a single European transport area – Towards a competitive and resource-efficient transport system. Brussels, 28.3.2011 COM(2011) 144 final (2011).*

41 Ida-Maja Hassellöv, Kjell Larsson and Eva-Lotta Sundblad, *Effekter på havsmiljön av att flytta över transporter från vägtrafik till sjöfart*. Havsmiljöinstitutets rapport nr 2019:5 (2019).

42 *Miljömålsberedningen, Havet och människan, SOU 2020:83. (Elanders Sverige AB 2020).*

5 Conclusion and Future Outlook

According to the international regulatory framework, scrubbers are allowed as a way to comply with the sulfur limitations in marine fuels. The narrow primary focus on reduction of emissions of sulphur oxides to the atmosphere implies overlooked potentially devastating consequences for the marine environment as the relative load of pollutants from scrubbers is enormous compared to other onboard generated liquid waste streams. As shown above, in 2018 99 ships in the Baltic Sea equipped with scrubbers caused a pollutant load one to two orders of magnitude higher than the load from all other liquid waste streams from all the more than 8000 ships operating in the area. To conclude, scrubber discharge water is a complex mixture of a variety of pollutants known to be harmful to the marine environment and wide-scale use of scrubbers includes all elements to qualify for inclusion in the next update of 'Late lessons from early warnings';⁴³ well-known environmental impact of the different components, high probability of synergetic effects, and a sudden shift to wide-scale use result in an imminent risk that the pressure of shipping on the marine environment is exacerbated. Not taking action implies a long-term risk with severe consequences in the marine ecosystem. For example, the pelagic second trophic, i.e. zooplankton, are very sensitive to scrubber water already at low concentrations.⁴⁴ Increased wide-scale use of scrubbers in the Baltic Sea could thereby cause perturbations in the ecosystem dynamics, similar to cascade effects following overfishing.⁴⁵

In a wider context, there is an immediate need for improved valuation of the environmental degradation following shipping activities, especially with respect to the marine environment. These figures then need to be included in assessments and comparisons of the environmental footprint from different modes of transport, especially in the light of transport strategies promoting a modal shift towards increased maritime shipping.

Finally, there is an urgent lack of information of the environmental impact of the new generation of residual fuel blends, Very Low Sulphur Fuel Oil and Ultra Low Sulphur Fuel Oil, often referred to as hybrid fuels.⁴⁶ These fuels

43 European Environment Agency, *Late lessons from early warnings: the precautionary principle 1896–2000. Environmental issue report No 22* (2001).

44 Koski, Stedmon and Trapp, (n 24).

45 Christian Möllmann and others, 'Effects of climate and overfishing on zooplankton dynamics and ecosystem structure: regime shifts, trophic cascade, and feedback loops in a simple ecosystem' (2008) 65 *ICES Journal of Marine Science* 302.

46 Lunde Hermansson and others, (n 38).

appeared on the market a few years prior to the 2020 regulations entered into force. Similar to the optimization of scrubber technology with respect to sulphur content, the hybrid fuels are blended to meet the sulphur limits, but the content of metals and organic pollutants that are likely present in the residual components is not regulated at all from an environment protection perspective. To reduce the risk of deterioration of the marine environment due to shipping, holistic approaches are needed to assess impacts of emissions to air and water, and human health at the same time. Fuel standards are today based on operational aspects, i.e. only physical or chemical properties that may impact the operation of the engine are specified. One concrete step towards improved understanding and motivating implementation of risk reduction strategies would be to also include risk assessment with respect to human health and the environment in future standards of marine fuels.

Table of Authorities

International Treaties

United Nations Convention on the Law of the Sea, Montego Bay (UNCLOS) (adopted 10 December 1982, entered into force 16 November 1994) 1833 UNTS 397.

EU Law

Directive 2000/60/EC establishing a framework for the Community action in the field of water policy (EU Water Framework Directive) [2000] OJ L 327/1.

Directive 2005/33/EC amending Directive 1999/32/EC (the European Sulphur Content of Marine Fuels Directive) [2005] OJ L191/59.

Directive 2008/56/EC establishing a framework for community action in the field of marine environmental policy [2008] OJ L164/19.

Bibliography

Books and Book Chapters

Bernes C and Naylor M, *Change beneath the surface: an in-depth look at Sweden's marine environment* (Swedish Environmental Protection Agency 2005) ISBN: 9162012460.

Official Documentation

EC, Note to the attention of the members of the European Sustainable Shipping Forum. Commission's views on the discharge of scrubber wash water and the updated table summarising the position of Member States on the acceptability of discharges of

- scrubber wash water – Agenda item 6.C ESSF of 26/1/2016. Directorate-General Environment. Directorate C – Quality of Life, Water & Air. Unit C.1 – Water and Unit C.3 – Air. Ref. Ares(2016)254855 – 18/01/2016., (2016).
- EC, White Paper. Roadmap to a single European transport area – Towards a competitive and resource-efficient transport system. Brussels, 28.3.2011 COM(2011) 144 final (2011).
- EMERGE, Evaluation, control and Mitigation of the EnviRonmental impacts of shipping Emissions (EU Horizon 2020 research and innovation programme under grant agreement No 874990. 2020).
- IMO, Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating thereto (MARPOL PROT 1997). Article 2. Addition of Annex VI, entitled Regulations for the prevention of Air Pollution from Ships, to the Convention. (1997).
- Miljömålsberedningen, Havet och människan, SOU 2020:83. (2020) ISBN: 978-91-38-25137-9, ISSN: 0375-250X.
- Rudén C, Future chemical risk management. Accounting for combination effects and assessing chemicals in groups, SOU 2019:45. (2019) ISBN: 978-91-38-24976-5, ISSN: 0375-250X.

Reports

- Comer B, Georgeff E and Osipova L, *Air emissions and water pollution discharges from ships with scrubbers*, ICCT Consulting Report, (2020). <https://theicct.org/publications/air-water-pollution-scrubbers-2020>.
- European Environment Agency, *Late lessons from early warnings: the precautionary principle 1896–2000. Environmental issue report No 22*, (2001).
- Hassellöv I-M and others, *ICES Viewpoint background document: Impact from exhaust gas cleaning systems (scrubbers) on the marine environment (Ad hoc)* (ICES Scientific Reports, (2020).
- Hassellöv I-M, Larsson K and Sundblad E-L, *Effekter på havsmiljön av att flytta över transporter från vägtrafik till sjöfart*, (2019) Report no: 2019:45. Swedish Institute of the Marine Environment.
- HELCOM, *State of the Baltic Sea – Second HELCOM holistic assessment 2011–2016. Baltic Sea Environment Proceedings 155*, (2018).
- Linders J and others, *Exhaust Gas Cleaning Systems – A roadmap to risk assessment. Report of the GESAMP Task Team on exhaust gas cleaning systems. Submitted to PPR 7 as document PPR 7/INF.23*, (2019).
- MEPC, *MEPC 70/INF.6. Assessment of fuel oil availability – final report. Submitted by Secretariat*, (2016).
- Osipova L, Georgeff E and Comer B, *Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit*, ICCT Consulting Report, (2021).

- Schildrop B, *IMO2020 Report # 2 More than enough quality MFO 0.5% if the price is right*, SEB (2018).
- Schildrop B, *Report New 2020 sulphur regulations for global shipping. Macro & FICC Research, Report SEB* (2018) <https://research.sebgroup.com/mficc-historic/a3cc1d70c4e2ff62c125865d00366acd.pdf>.

Journal Articles

- Corbett JJ and Fischbeck P, 'Emissions from ships' (1997) 278 *Science* 823. DOI: 10.1126/science.278.5339.823.
- Endres S and others, 'A New Perspective at the Ship-Air-Sea-Interface: The Environmental Impacts of Exhaust Gas Scrubber Discharge' (2018) 5 *Frontiers in Marine Science*. 139. DOI: 10.3389/fmars.2018.00139.
- Halpern BS and others, 'Recent pace of change in human impact on the world's ocean' (2019) 9 *Scientific Reports* 11609. <https://doi.org/10.1038/s41598-019-47201-9>.
- Hassellöv I-M and others, 'Shipping contributes to ocean acidification' (2013) 40 *Geophysical Research Letters* 2731–2736. DOI: <https://doi.org/10.1002/grl.50521>.
- Jalkanen JP and others, 'Modeling of discharges from Baltic Sea shipping' (2021) *Ocean Science Discussions* 1–54. DOI: <https://doi.org/10.5194/os-2020-99>.
- Koski M, Stedmon C and Trapp S, 'Ecological effects of scrubber water discharge on coastal plankton: Potential synergistic effects of contaminants reduce survival and feeding of the copepod *Acartia tonsa*' (2017) 129 *Marine Environmental Research* 374.
- Lunde Hermansson A and others, 'Comparing emissions of polyaromatic hydrocarbons and metals from marine fuels and scrubbers' (2021) 97 *Transportation Research Part D: Transport and Environment* 102912. <https://doi.org/10.1016/j.trd.2021.102912>.
- Möllumann C and others, 'Effects of climate and overfishing on zooplankton dynamics and ecosystem structure: regime shifts, trophic cascade, and feedback loops in a simple ecosystem' (2008) 65 *ICES Journal of Marine Science* 302. DOI: 10.1093/icesjms/fsm197.
- Raudsepp U and others, 'Shipborne nutrient dynamics and impact on the eutrophication in the Baltic Sea' (2019) 671 *Science of the Total Environment* 189. DOI: 10.1016/j.scitotenv.2019.03.264.
- Teuchies J and others, 'The impact of scrubber discharge on the water quality in estuaries and ports' (2020) 32 *Environmental Sciences Europe* 103. DOI: <https://doi.org/10.1186/s12302-020-00380-z>.
- Ytreberg E and others, 'Effects of scrubber washwater discharge on microplankton in the Baltic Sea' (2019) 145 *Marine Pollution Bulletin* 316. <https://doi.org/10.1016/j.marpolbul.2019.05.023>.

Others

Personal communication, J.B. Fisher, Goldman Sachs Commodities Research, e-mail to author.

DNV GL, 'Alternative Fuel Insight' (2021) <<https://afi.dnvgl.com/>> accessed 10 March 2021.

Ytreberg E, Lunde Hermansson A and Hassellöv I-M, *Deliverable 2.1 – Database and analysis on waste stream pollutant concentrations, and emission factors. EMERGE: Evaluation, control and Mitigation of the Environmental impacts of shipping Emissions, funded by European Union's Horizon 2020 research and innovation programme under grant agreement No 874990, (2020).*