CSHIPP
Clean Shipping Project Platform

Report on knowledge gaps and research strategies on the environmental impacts of shipping and their mitigation

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Report on knowledge gaps and research strategies on the environmental impacts of shipping and their mitigation

Based on the national consultations and synthesis work in CSHIPP GA 2.1 – GA 2.3

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This report is an output of Clean Shipping Project Platform (CSHIPP). It briefly reviews current clean shipping policies and their environmental effects and highlights important knowledge gaps. Possible strategies for research on impacts of shipping on the environment and climate have also been outlined. Results of the CSHIPP projects are published in ca. 20 scientific papers. The impacts of shipping emissions on atmospheric pollution, discharges of water contaminants and emissions of noise energy to the sea have been briefly summarised in three short reports which complement this report. Best practices in remote compliance monitoring of sulphur emissions by ships in sulphur emission control areas (SECA) together with available monitoring data and results from the last 5 years have been summarised in another dedicated CSHIPP report. That report also discusses whether the same method can be applied to control IMO limits for emissions of NOx.

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Policy analysis

The fuel sulphur regulations successively introduced and tightened by IMO have decreased the contribution of shipping to air pollution with SO_2 and particulate matter and to deposition of sulphur on ecosystems significantly. The SECA 0.1% fuel-sulfur-content limit introduced in 2015 decreased the negative impacts on human health in the Baltic Sea region related to shipping emissions by ca. 35% (Barregård et al. 2019) and the shipping-related sulphur deposition decreased by about a factor of 10. Since the regions most heavily impacted by this deposition do not have extensive problems with acidification, this large decrease is reflected in relatively modest, yet important, improvements in terms of reduction of areas with exceeded critical loads for acidification (Repka et al. 2021). The global 0.5% fuel-sulphur-content limit introduced in 2020 is expected to bring similar improvements in other regions, such as the Mediterranean Sea or the European Atlantic coast, but is not expected to bring further environmental improvements in the Baltic Sea region, which is already protected by the SECA regulation.

An intensively discussed and researched question related to the fuel sulphur regulation concerns the use of exhaust gas aftertreatment, i.e. scrubbers and the use of high sulphur heavy fuel oil (HFO) as an alternative to the use of low sulphur marine gas oil. Scrubbers, if they are of open-loop type, produce large volumes of acidified and contaminated wash water which is disposed directly to the sea, transferring pollution from one environmental compartment to the other. Also atmospheric emissions of primary particulate matter, i.e. soot and ash particles bearing metals, sulphate, and organics including PAHs, from the combustion of HFO with aftertreatment are higher than primary particulate matter emitted from combustion of MGO. This will reduce the health-impact benefits of the regulation, especially in harbour cities.

The stringent sulphur limitations require a good compliance rate in order to be effective. If the compliance rate is low, this will quickly lead to significant increases in overall SO_X emissions from ships and consequently ambient levels of the associated particulate matter. In Northern Europe, compliance monitoring with help of remote sensing is conducted by several countries (Mellqvist et al., 2020; Beecken et al., 2014). The current legislation requires evidence in the form of analysis of a fuel sample from the ship for penalisation of its non-compliance. Enforcement of the regulation in case of vessels using the exhaust aftertreatment alternative is based on onboard measurements and self-reporting.

Even though the fuel sulphur regulations decreased the negative environmental impacts of shipping significantly, they still remain important. To a large extent this is due to the high emissions of nitrogen oxides (NO_X). Currently, NO_X accounts for the largest part of the total environmental impact, including negative health impacts and eutrophication of marine and land ecosystems (Ytreberg et al., 2020; 2021). In 2021, nitrogen emission control areas (NECA) entered into force in the Baltic Sea and North Sea regions. However, as it applies only to ships keel-laid in 2021 and later, it will have full effect first in ca. 20 years, when many old ships will be replaced. Local or regional measures, such as refundable emission payment (REP) scheme or financial investments supporting NOx emission abatement technologies would speed up the emissions reduction (Parsmo et al., 2017).

The NECA regulation is enforced through certificates of in-service compliance of the engine in accordance with the requirements of IMO's NOx Technical Code 2008. The question of how to monitor actual compliance of the vessels operating in NECAs with the current legislation is subject of intensive research and discussion.

There is an ongoing discussion within IMO about introducing regulation for PM emissions of Black Carbon, especially for ships operating in the Arctic, to mitigate its strong climate warming impact in this sensitive region. So far, the problem lies in how to define the Black Carbon associated with light-absorbing properties of soot, and subsequently what methods to use for emission measurements as well as in potential engine certifications. This also determines whether it would be possible to carry out compliance monitoring from remote.

To mitigate climate change, MARPOL Annex VI introduces two mandatory mechanisms intended to ensure an energy efficiency standard for ships: the Energy Efficiency Design Index (EEDI) for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships.

In 2018, the IMO adopted an Initial Strategy on the reduction of GHG emissions from ships, with the target to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008. The strategy calls for strengthening the EEDI requirements and further operational efficiency measures and speed reductions, measures to address CH_4 emissions, alternative low-carbon and zero carbon fuels, as well as market-based measures (e.g. carbon trading schemes). Regarding the operational energy efficiency, the logistics of the Baltic Sea Area is dependent on the RoRo and RoPax vessels that are fast but inefficient compared to e.g. container or general cargo vessels. At some point it may be necessary to rethink the just-in-time logistics to reach higher operational energy effectivisation, both regarding the sea transport and the entire logistics chain. The fuel consumption reduction measures would bring co-benefits in reducing air pollution problems, an approximately twice as high energy efficiency index than required by the EEDI rules would result in roughly 30% less impacts on human health and ecosystems caused by shipping (Moldanová et al., 2018). For other measures, as some of the abatement techniques and alternative fuels, careful investigation of their secondary impacts on air pollution, land ecosystems as well as marine ecosystems is needed to anticipate potential negative side effects. One example of a measure requiring caution is ammonia as an alternative fuel.

Regarding the direct discharges of harmful substances from shipping to the marine environment, regulation of several sources of releases remains weak and these sources are expected to increase with increasing shipping in the future. While discharge of sewage is regulated and will be banned in the Baltic Sea after the year 2023, there are currently no plans for regulating discharges of grey water which contribute to water pollution with similar loads of nutrients and a large number of contaminant species. Currently, discharges of contaminated acidic scrubber wash water are becoming an emerging issue as discussed above in context with the fuel sulphur regulation. Shipping in the Baltic Sea contributes significantly to

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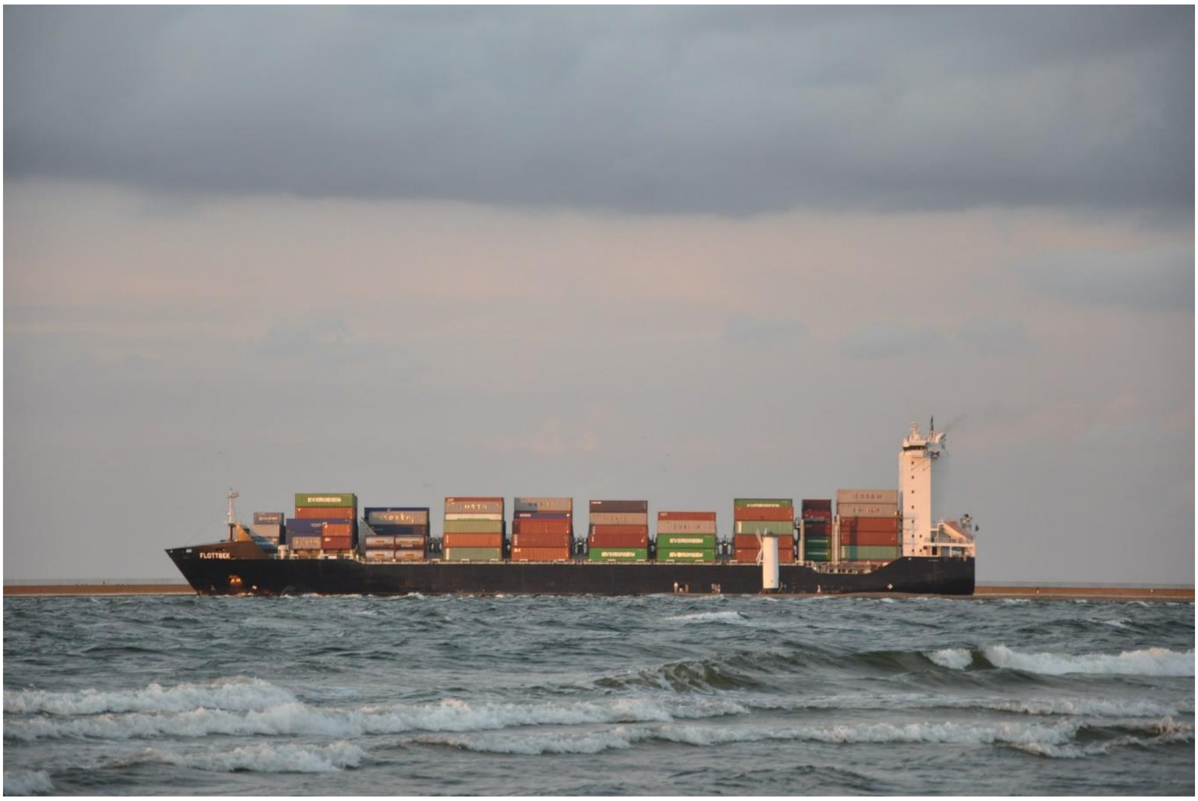
exceedances of the Environmental Quality Standards of the Water Framework Directive, most importantly for copper, for which the main source is leakage of antifouling paint. Also in this case, there are currently no plans for legislation which would reduce this source of pollution.

There are several things which need to be considered before noise can be efficiently managed. Currently, noise is not routinely monitored for civilian purposes in European sea regions. Also, legal expertise is needed to assess whether current environmental regulations at IMO can be extended to cover impacts of immaterial discharges (noise/energy) on animals. Currently, this is unclear. Voluntary guidelines exist for silent vessel designs, but vessel design criteria do not require noise mitigation. Noise should be considered during the design phase of new vessels, which requires close cooperation of IMO, classification societies, maritime authorities, naval architects and other relevant stakeholders.



Current knowledge gaps and research directions

The assessment framework developed in the CSHIPP projects needs to be seen as a basis which will be continuously developing as the situation changes and new knowledge is becoming available. The most important areas where research effort is needed include i) a continuous update of the description of ships in the traffic models concerning fuel type, use of engines in different modes as well as the use of abatement measures following the technological and policy development and ii) improvement, update and development of new emission factors of air pollutants, underwater noise energy, specific volumes of the different waste streams (grey water, black water, food waste, etc.) as well as concentrations of nutrients and contaminants in these streams and their discharge patterns. The latter requires intensive measurements, both in the exhaust and in the different waste streams.

For an evaluation of the recent fuel sulphur legislation, impacts of open and closed-loop scrubbers on the marine environment need to be investigated along with comparison of emissions of PM to the atmosphere from ships using HFO and scrubbers with emissions from ships using low-sulphur fuel. For a proper evaluation of the NECA regulation, more knowledge on impacts of NOx emission abatement technologies (selective catalytic reduction - SCR and emission-gas recirculation - EGR) on emissions of other pollutants but NOx (mainly PM and NH3 slip for SCR) is needed.

Regarding NECA compliance monitoring, NO_X measurements are assessed in the CSHIPP report: "Best practice report on compliance monitoring of ships with respect to current and future IMO regulation". Preliminary results indicate that remote measurements could be used for ships operating at high loads while ships at low loads will be more difficult to measure. The main difficulty lies in the fact that the IMO NOx technical code requires that the emission must be calculated as a weighted average of the values at four different engine loads, which cannot easily be measured remotely.

Compliance monitoring of regulations on methane slip during combustion of LNG or LBG is also difficult. The exhaust concentrations are generally small and mixed with the 2 ppm atmospheric background methane levels, it is uncertain whether these levels can be detected by remote measurements. Further work is also needed to understand uncertainties involved in the measurement technologies.

The models used for the calculation of the environmental state also need further development and validation: An important issue specific for modelling air pollution from shipping are small-scale processes affecting concentrated gases and particles in ship plumes and intensive air-sea exchange through turbulence behind the ships. Further, the spatial model resolution is still a compromise between level of detail and available computer power. Calculations with high resolution are often done for small domains, inadequately considering the important long-range transported contribution to air pollution. Regional models take these contributions into account but their resolution is too coarse for covering spatial inhomogeneities. More harbour-scale studies analysing also the impact of regional shipping in multi-nested applications, such as performed by Tang et al. (2020) and Ramacher et al. (2020) are needed. Interannual variability in meteorology and also climate change will affect air pollution, deposition, and thereby health impacts over the years. This is only partly taken into account in calculations performed to date. Modelling of atmospheric input of PAHs and some metals from shipping to the sea, which often have multiple on-board sources, needs to be developed to enable comparison of effects when these pollutants are emitted to the atmosphere or directly to the sea.

In oceanic modelling, a description of physical effects of induced mixing in ship lanes, improvements in the description of biogeochemical processes as well as the determination of synergistic effects, e.g. of toxicity of different contaminants and acidification have been identified as the main tasks. Measurements in the vicinity of shipping lanes and harbours are needed for model development and verification purposes as well as for a better understanding of these processes.

Regarding underwater noise, the noise source model developed in BONUS SHEBA needs to be improved for some vessel categories, especially passenger and feeder vessels, and it needs to be extended to more engine and propeller types. There exists a conflict between energy efficient and silent vessel design, which needs to be considered in more detail. Both, technical (e.g. propeller design) and operational (e.g. slow steaming) measures for reducing underwater noise need to be investigated. Noise propagation modelling has only been performed for a limited area due to its computational requirements. Modelling on a regional scale is still missing. Regular monitoring of underwater noise needs to be developed. Currently, only scattered research projects perform noise monitoring, but there is a clear need for an observation network, which is similar to the coverage required for atmospheric pollution monitoring. It is difficult to conduct impact assessment of noise if only some of the relevant sources of noise pollution are known. This inevitably leads to the situation where noise exposure is incomplete and needs further work to cover all sources.

Assessments of health impacts and impacts on natural land ecosystems have been performed along the methodology used in EU Thematic Strategy on Air Pollution (TSAP) and it is important to keep the methodology updated as more knowledge is included in the TSAP. Health impact studies are subject to uncertainty, e.g. more research is needed to disentangle the health effects from NO_2 and primary particulate matter, and secondary pollutants like O3 and ultrafine particles.

Linkages between environmental concentrations of pollutants, contaminants, and noise energy levels and environmental changes, e.g. in biodiversity, are seldom quantitative and a focused effort is needed, both, in marine and terrestrial ecosystem research to gain more knowledge. Importantly, cocktail and synergistic effects of e.g. multiple contaminants or different contaminants and acidification, needs to be quantified. This is a wide research area not limited to shipping, however, important impacts have been mapped in the BONUS SHEBA project. Links between pollution and ecosystem services are in most cases only qualitative and not well understood. There is also a lack of established methods for monetization of benefits of policy options.

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