Emissions from Ships Reduction

This POSTnote gives an overview of the impact of emissions to the air from ships, to densely populated coastal areas and the sensitive environment of coastal waters. It presents current policies and international regulations for the reduction of ship emissions and latest research findings about the effectiveness of existing measures. It examines the role of port and city authorities in ship emission management and emission reduction decision processes.

International shipping transport, delivers eighty percent of goods globally [1]. Shipping is still the most energy efficient way of transportation. Sustainable ports and shipping industry are essential trade lines, which is why ports are located in densely populated cities and coastal regions. Port authorities and city governments have recognized the importance of city-port collaboration, the result of which is the planning of green areas around ports, including preservation of habitats and integration of ports to urban areas.

Shipping activity however, accounts for exhaust emissions that present a serious threat to human health, the environment and lead to the formation of greenhouse gases and black carbon. Shipping in the UK is carrying people and goods, around the UK coast as well as through inland waters and to offshore installations.

Sulphur oxides and *nitrogen oxides* are responsible for acidification of the oceans as well as eutrophication of enclosed bays in ports, river estuaries and coastal areas.

These waters have less intake of fresh water from the ocean and cumulate sulphur and nitrogen oxides, that dissolve in water and create nutrients.

Nutrients from nitrogen oxides feed excess of algae, causing algae blooms, which consume oxygen needed for biodiversity in rivers and seas. Die outs of excess of algae, causes more oxygen loss and die outs of fish and other marine life.

This chain reaction of toxic processes, known as eutrophication, will suffocate diverse marine life, but stimulate spread of gelatinous creatures and algae, forming swamp like, lifeless waters.

Shipping Emissions Impact

Approximately 70 per cent of the emissions from ships occur within 400km of land. Due to the transboundary nature of emission gases, ships can contribute to pollution hundreds of kilometres inland [2] The greenhouse gas (GHG) emissions, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (NO_x) have increased almost 10 per cent since 2012 levels.[3]

Emissions from ships using diesel engines and conventional fuels, account for pollutant species like carbon dioxide (CO_2), sulphur oxides (SO_x) nitrogen oxides (NO_x) and black carbon particulates. Carbon dioxide is causing global warming, while sulphur and nitrogen oxides account for an increase in human mortality [4]. Nitrogen and sulphur oxides are reacting in the atmosphere, forming tiny particles, particulate matter ($PM_{2.5}$). Such tiny soot particles are small enough to pass through lung tissues and enter the blood, which can cause cardiovascular diseases, asthma, and lung diseases [5].

Emission Control Areas (ECA)

To mitigate risks from ship emissions the Government has established Sulphur and Nitrogen Oxides Emission Control Areas (SECA and NECA) in cooperation with the International

Maritime Organisation (IMO). Sulphur oxides are expected to reduce significantly but not completely, as the content of sulphur in the marine fuel has recently been reduced to 0.5 percent globally by new IMO regulations and to 0.1 percent in Emission Control Areas. [3,6], figure 1.

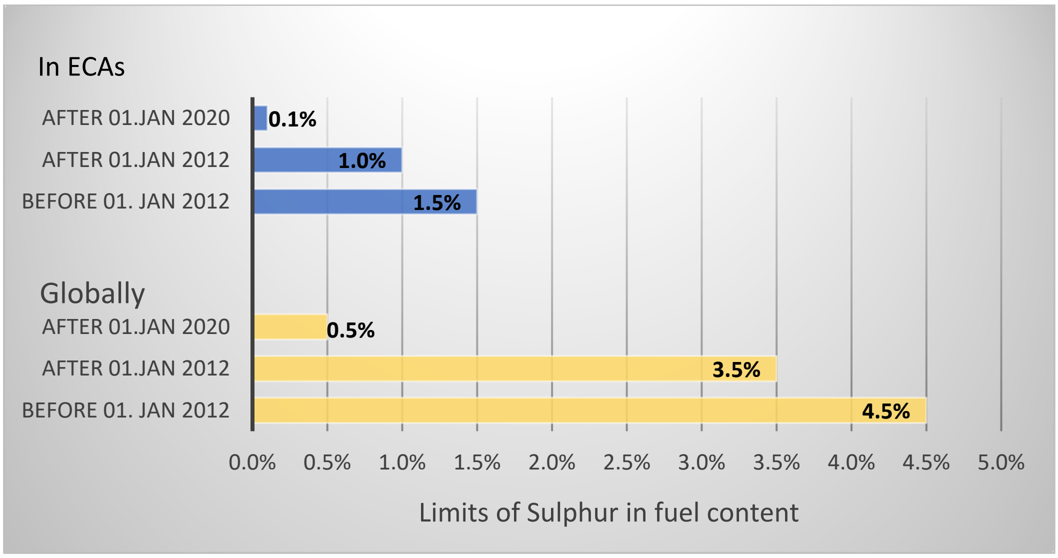

Figure 1: Changes in reduction of sulphur in fuel content, globally and in ECAs

Ships outside the ECA areas need to comply to Tier II standard, which allows 70 percent higher emissions compared to Tier III regulation in ECA regions [3,7]. Ship owners, driven by competitive markets, make savings on high prices for very low sulphur and low sulphur fuel by using less refined fuels with high sulphur content and engines that produce very high levels of nitrogen oxides [8]. *Technical measures* which reduce emissions, work well in test bed conditions when ships are issued certificates for emissions. However, there is not enough evidence of application or efficiency of these technical measures in sea going conditions.

Sulphur Oxides SO_x

Oxides of sulphur in ship exhaust emissions are the direct result of sulphur content in fuel. The sulphur oxidises during combustion to SO_2 and further to 3-5% amount of SO_3, depending on the combustion conditions in the cylinder. Further oxidation occurs in the exhaust system and atmosphere. SO_3 reacts with water vapour to form sulphuric acid H_2SO_4 and SO_x, is harmful to human health at concentrations higher than 20 parts per billion (ppb) and lethal at levels measured at exhaust, which is 500 ppb.

> *Technical measures* include the adoption of cleaner fuels, adding closed-loop 'scrubbers' or other exhaust gas cleaning devices to ships (for SO_x), SCR systems (for NO_x), slow steaming, and wider use of alternative sources of energy including wind propulsion, battery-electric propulsion, alternative fuels like ammonia and hydrogen, and port-side electricity.

SO_x regulations

In the past two decades, IMO global regulations have enforced considerable reductions in the Sulphur content of marine fuels, and subsequently, the allowable content of SO_x in the exhaust emissions. Requirements related to SO_x emissions are governed by MARPOL, the International Convention for the Prevention of Pollution from Ships, Annex VI, Regulation 14[9]. This regulation sets limits of sulphur content in fuel, globally and in Emission Control Areas (ECAs), which have more stringent requirements for SO_x emissions and sulphur content in fuel (IMO 2020 Sulphur Cap), as presented in figure 1.

Technical measures for SO_x

Current research that the expected results of IMO 2020 Sulphur Cap are not at the desirable level and IMO will need to develop new policies inclusive of alternative fuels [10] and emission reduction technical measures. The immediate action could be taken to reduce emissions from ships significantly, by slow steaming, as it is overall accepted that ships have significantly higher fuel efficiency when sailing at lower speeds.

Other methods for SOx abatement include:

1) using scrubbers, 2) using low sulphur fuels or 3) converting marine diesel engine to LNG.

Scrubber, in simplest terms, aims to wash the exhaust gases with sea or fresh water and, in this way, the emission is trapped in a mixture, which is called as sludge, instead of being released into the air. Although, the use of scrubber is a common and successful emission prevention method, it is an issue worth examining especially in terms of production of additional CO_2, sludge disposal and costs.

Nitrogen Oxides NO_x

Unlike sulphur oxides that can be regulated by reduction of sulphur content in fuel, nitrogen oxides form in a reaction during combustion. Measured at the exhaust of marine diesel engines, nitrogen oxide or NO_x emission consists of 95% nitric oxide (NO) and 5% nitrogen dioxide (NO_2). This 5% of NO_2 forms during the oxidation of NO in the engine cylinder, which is dependant of combustion temperature and becomes significant above 1200◦C and rapid over 1500◦C [11].

NO_x regulations

Nitrogen oxides (NO_x) reduction is now regulated by MARPOL 73/78, the International Convention for the Prevention of Pollution from Ships, that was established under the auspice of IMO. MARPOL 73/78 consists of 6 annexes, and Annex-VI covers reduction of ship emissions to the air, where Regulation 13 has focus on NO_x emissions. Regulation 13 limits Nitrogen oxides (NOx) by IMO Tier III standard, which requires all marine engines built after 2016, with installed main engine power greater than 130kW to reduce NOx emissions for 80 percent compared to Tier I level [11].

NOx technical measures

The control of NOx emissions, and secondary PM formation, is more complex as NOx forms after the combustion process. Reduction in NOx requires changes in the design of the engine and/or the treatment of the engine's exhaust. The scrubber removes damaging contaminants like particulate matter, nitrogen and sulphur oxides, and EGR recirculates exhaust gas back to the loop, resulting in lower temperatures in the combustion process and consequentially a reduction in NO_x.

Emission Reduction Targets

Although, these measures contribute to a significant reduction in ship emissions, research shows it is not enough to comply with Paris agreement to keep the global temperature warming well below 1.5 degrees C. The International Maritime Organisation has set the target to half the emissions from shipping by 2050, compared to the levels from 2008 and eventually phase the emission out completely. The Prime Minister's 10-point plan sets the target to a higher more ambitious level and expects shipping in the UK to reach NetZero by 2050 [12].

Research in Ship Emissions Estimates to Monitor Impact

Novel methodology has been established that can enable ports and policy makers to estimate ship emissions simply but accurately for the voyage between the port of departure, all the way to the port of destination [13]. The widely accessible Automatic Ship Identification System (AIS) uses satellite and land-based stations to locate transceivers installed on each ship larger then 300GT, to establish ship activity across the globe. Methodologies exist to use AIS data to estimate emissions for any location or ship, globally. This understanding could lead to allocation of emission footprints to stakeholders that are accountable and higher levels of control and understanding of the local and global impact of emissions from ships.

Recommendations

Stakeholders in shipping need to be accounted for the emission footprint, for the full length of the ship's voyage. Emissions need to be accounted for cargo, for the full journey, and policies considered to stimulate the reduction of emissions from ships.

Recommended actions to be taken by governments globally include [14]:

- Develop a short sea shipping strategy to transition to zero emission vessels, starting with converting ferries, Ro-Ro and cruise ships to battery-electric propulsion and converting to hydrogen propulsion for cargo ships.
- Implement a 'zero emission at berth standard' in all ports.
- Transpose the international IMO standards for NOx emissions into law and adopt additional stricter legislation to address NOx emissions from the existing fleet.
- Extend SECA and NECA standards to the rest of the EU seas: Mediterranean, Adriatic, Black and Irish Seas and the North East Atlantic.
- Monitor whether proper enforcement procedures are adopted, in order to ensure compliance with the standards. For sulphur, a global ban on bunkering of non-compliant fuels (unless ships are fitted with adequate technical measures) and a global mandate for continuous emissions monitoring systems (CEMSs) are the most promising methods of enforcement. The latter would serve for NOx enforcement, too.
- Adopt market-based measures to make polluters pay a fair price for the emissions the shipping sector is responsible for.

References

[1]Toscano, D. & Murena, F. (2019) Atmospheric ship emissions in ports: A review. Correlation with data of ship traffic. Atmospheric Environment: X 4.

[2] Andersson, K., Brynolf, S., Lindgren, J.F. & Wilewska-Bien, M. (2016) Shipping and the Environment. Karin Andersson, Selma Brynolf, J. Fredrik Lindgren, & Magda Wilewska-Bien (eds.). Berlin, Heidelberg: Springer Berlin Heidelberg.

[3] IMO International Maritime Organization (2020) 4th IMO Greenhouse Gas Study 2020. Mepc 75/7/15 74.

[4] Corbett, J.J., Winebrake, J.J., Green, E.H., Kasibhatla, P., Eyring, V. & Lauer, A. (2007) Mortality from ship emissions: A global assessment. Environmental Science and Technology. 41 (24), 8512–8518.

[5] Apte, J.S., Brauer, M., Cohen, A.J., Ezzati, M. & Pope, C.A. (2018) Ambient PM 2.5 Reduces Global and Regional Life Expectancy. Environmental Science & Technology Letters. 5 (9), acs.estlett.8b00360.

[6] The Clean Shipping Coalition; IMO International Maritime Organization (2016) FURTHER TECHNICAL AND OPERATIONAL MEASURES FOR ENHANCING THE ENERGY EFFICIENCY OF INTERNATIONAL SHIPPING. 5.

[7] Brynolf, S., Magnusson, M., Fridell, E. & Andersson, K. (2014) Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels. Transportation Research Part D: Transport and Environment. 286–18.

[8] Abadie, L.M., Goicoechea, N. & Galarraga, I. (2017) Adapting the shipping sector to stricter emissions regulations: Fuel switching or installing a scrubber? Transportation Research Part D: Transport and Environment. 57 (October), 237–250.

[9] IMO (International Maritime Organization) (2008) MARPOL ANNEX VI, Regulation 14. Available from: https://www.egcsa.com/regulatory/marpol-annex-vi-regulation-14/ (Accessed 28 April 2021).

[10] Bilgili, L. (2021) Life cycle comparison of marine fuels for IMO 2020 Sulphur Cap. *Science of the Total Environment*. 774145719.

[11] EGCSA (2014) NOx Reduction by Exhaust Gas Recirculation – MAN explains. Available from: https://www.egcsa.com/exhaust-gas-recirculation-explained/ (Accessed 19 April 2021).

[12] IMO International Maritime Organization (2020) 4th IMO Greenhouse Gas Study 2020. Mepc 75/7/15 74

[13] Energy White Paper: Powering our net zero future (2020). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf (Accessed: 12th April 2021). (ISBN 978-1-5286-2219-6, CCS0220144090)

[14] Topic, T., Murphy, A.J., Pazouki, K. & Norman, R. (2021) Assessment of ship emissions in coastal waters using spatial projections of ship tracks, ship voyage and engine specification data. Cleaner Engineering and Technology. 2100089.

[15] European Federation for Transport and Environment AISBL (2020) Shipping’s impact on air quality. Available from: https://www.transportenvironment.org/what-we-do/shipping-and-environment/shipping’s-impact-air-quality (Accessed 28 April 2021).