Reducing the sulphur content of marine fuels

Could the cure be worse than the disease?

IMO's MARPOL Annex VI legislation has so far been based on the concept of SECAs, i.e. it seeks targeted sulphur reductions in those specific areas where emission density is high and sulphur impacts from ships are comparable to those from land-based sources. By focusing on emissions where they are the most harmful, rather than setting a global sulphur cap for all marine fuels, IMO has enabled reductions to have maximum benefit for human health and the environment while remaining cost-effective.

As the outcome of the Annex VI review process, IMO's MEPC 58 recently adopted a progressive though dramatic reduction in fuel sulphur levels in SECAs, as well as the future introduction of a stringent global sulphur cap set at one-third of current SECA levels. This, it is argued, would be precautionary with respect to possible effects on human health and the environment.

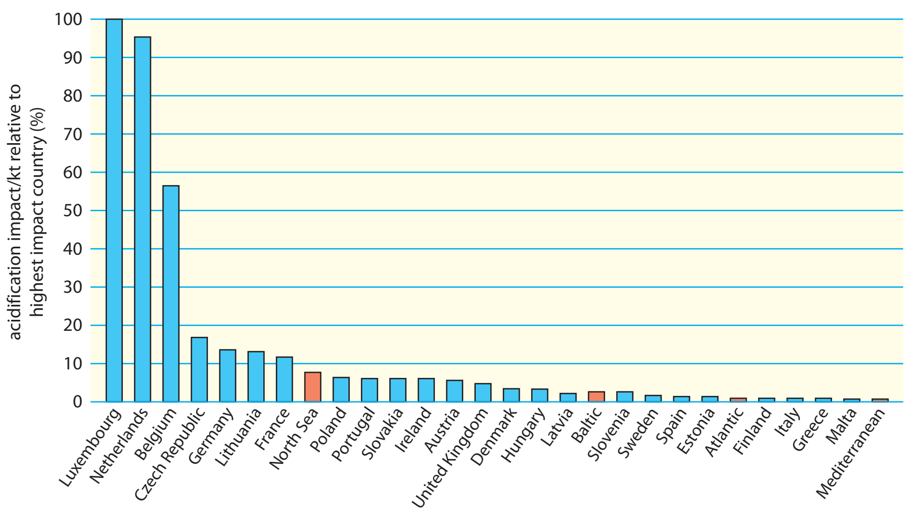
There are of course a number of significant implications of such a move, not least the economic and security of supply issues which have been highlighted by CONCAWE in a recent study[1]. This simplistic view is open to challenge from the point of view of both the air quality benefits of such a global sulphur emission reduction and the undesirable effects that it may have on global warming. This article explores some of the available scientific evidence to challenge the notion that this new regulation is 'precautionary' from an environmental perspective.

Air quality impacts

Proximity of emissions to sensitive receptors is an important factor

Figures 1 and 2, abstracted from a recent CONCAWE publication[2], clearly support the current SECA-based approach. Figure 1 shows the relative impact on

Figure 1 Contribution to exceedances of acid critical loads in the EU per unit of SO_2 emissions



[1] Techno-economic analysis of the impact of the reduction of sulphur content of residual marine fuels in Europe. *CONCAWE Report 2/06.*

[2] Impact on the EU of SO_x, NO_x and primary $PM_{2.5}$ emissions from shipping in the Mediterranean Sea: a summary of the findings of the Euro Delta Project. *CONCAWE Report 1/08.*

exceedances of critical loads for acidification of a unit of SO_2 emitted in different European countries and sea areas. Geographical location of emissions and emission density both have a significant influence on the relative impact of emissions. For example a unit of SO_2 emitted in the North Sea has more than fifty times the impact of the same unit of SO_2 emitted in the Mediterranean Sea. This is why, as part of its strategy to combat acidification in the second half of the 1990s, the EU successfully applied for the North Sea to be recognised as a SECA, but did not apply for the Mediterranean Sea to be so designated, in spite of the higher quantity of emissions there.

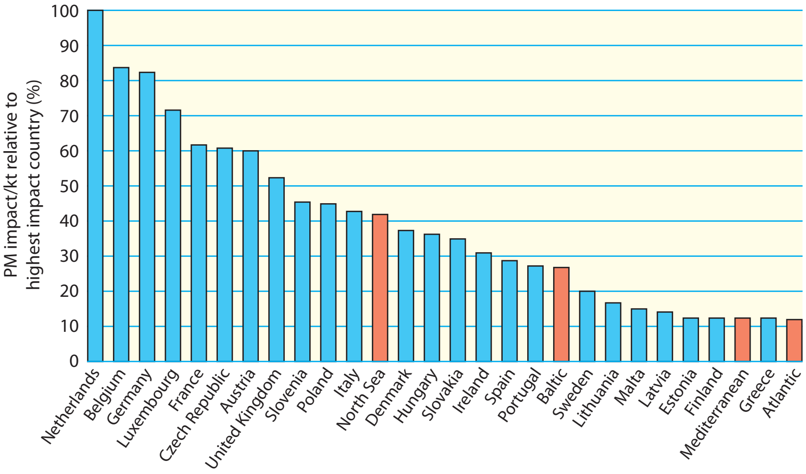
Figure 2 shows the estimated[3] impact on human health of fine particulates derived from a unit of SO_2 emitted in individual European countries and sea areas compared to the highest impact country. Geographical location of emissions and emission density again have a significant influence on their relative impact. Here, it is proximity to heavily populated areas rather than sensitive ecosystems that counts. For example a unit of SO_2 emissions from Germany has about twice the impact of a unit of SO_2 emissions from the North Sea and about seven times that of the Mediterranean Sea.

This SECA-focused approach recognises the need to account for the proximity of emissions to sensitive receptors. It is consistent with the design of cost-effective policies based on Integrated Assessment Modelling, which has underpinned European environmental legislation related to air pollution for more than a decade.

This SECA approach recognises that both land- and sea-based sources should be considered together in order to solve environmental problems.

[3] *Within the framework of the Clean Air For Europe (CAFE) programme and following the advice of WHO pending more data becoming available, it is assumed that all particles, irrespective of composition, pose a risk to human health. The 'health' index used in Europe is the number of life years of the whole population. Work is continuing to establish whether particle composition is important. It is widely believed that directly-emitted combustion particles are more harmful than the secondary sulphate particles controlled by SECA measures.*

Figure 2 Impact of fine particulates derived from SO_2 emissions on overall EU population per unit of SO_2 emissions



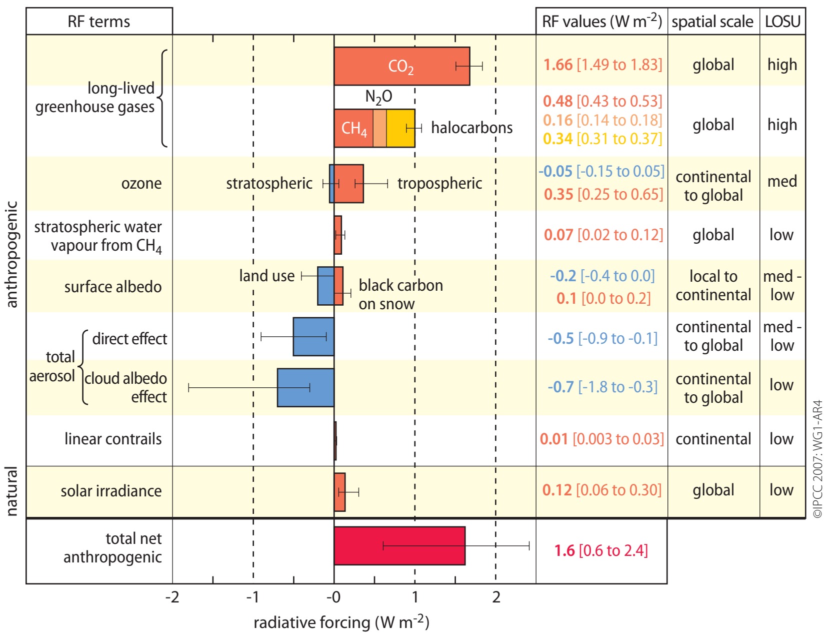
Climate impacts

The role of sulphate aerosols in global cooling

It has long been understood that sulphate aerosols in the atmosphere (e.g. from volcanic eruptions) induce a 'global cooling' signal by modifying the radiation heat balance.

Figure 3, abstracted from the fourth IPCC Assessment Report[4], provides an overall perspective on radiative

Figure 3 Summary of radiation forcing (RF) from all sources



[4] *Summary of radiation forcing from all sources. IPCC* Fourth Assessment Report, *Work Package 1, Summary for Policymakers.*

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forcing components in the global atmosphere that contribute to either global warming (positive forcing) or cooling (negative forcing). This figure shows that the largest negative forcing comes from aerosols of anthropogenic origin and has both a direct and indirect forcing component. Direct forcing is due to the aerosol particles (mainly sulphates) themselves, and indirect forcing is due to condensation of water around very fine particles altering cloud cover and cloud properties.

Shipping emissions make a large contribution to both direct and indirect aerosol effects. Ocean areas present a good radiation absorbing surface compared with land and any reduction in cloud cover will increase heat uptake. Because shipping is widely distributed (mostly in the Northern Hemisphere) the direct and indirect aerosol effects due to SO_2 emissions have a potent negative forcing effect readily measured by satellite[5].

Nitrogen oxides emissions from ships also play a role. NO_x participates in the formation of ozone which, in the lower part of the atmosphere, acts as a greenhouse gas with positive forcing (Figure 3). However, the chemical reactions involved also destroy some atmospheric methane which is a potent greenhouse gas. These reactions also promote the early oxidation of SO_2 to sulphate, contributing to the cooling effect.

Climate models have been used to calculate the degree of forcing for each of these different components. Eyring *et al.*[6] looked at direct effects and found that the direct negative forcing due to sulphate aerosols and the removal of methane roughly balanced the positive forcing due to CO_2 emissions from ships (Table 1). They also conjectured that the indirect sulphate effect (influence on clouds) would be at least as large as the direct sulphate contribution, leading to a net cooling effect.

Lauer *et al.*[7] found a huge effect of ship emissions on indirect forcing, an order of magnitude larger than all other effects and amounting to between 17% and 39% of the global radiation budget. Control calculations assuming zero sulphur in marine fuel reduced this effect by 75%, confirming that sulphur emissions from ships are key. The results are shown in Figure 4.

In a study sponsored by CONCAWE, the Massachusetts Institute of Technology (MIT) also ran two ship emission scenarios (a 'base case' and a 'zero sulphur emissions from ships case') to quantify the magnitude of the sulphate cooling signal. They found an averaged direct negative forcing of –12.5 mW/m^2 which is consistent with other studies. To provide a policy perspective, they

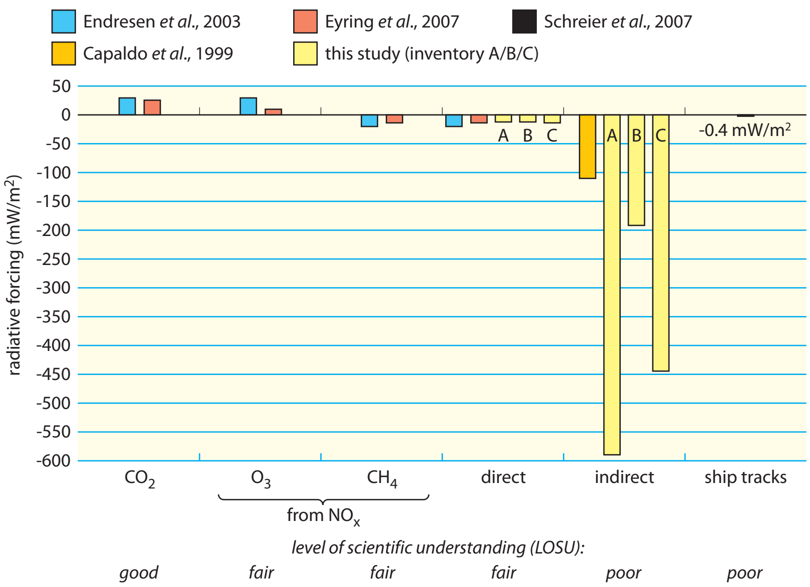
Table 1 Shipping contributions to direct forcing effects

Scenario	Ozone *(mW/m^2)*	Sulphate* *(mW/m^2)*	Methane* *(mW/m^2)*	CO_2 *(mW/m^2)*
2000 base	9.8 ± 2	-14	-14	26
2030 constant ship emissions (2000)	7.9 ± 1.4	-13	-13	24
2030 high growth ships (2.2% per annum)	13.6 ± 2.3	-26	-21	46

* A negative sign means a cooling effect.

After Eyring *et al.*

Figure 4 Indirect forcing from ship emissions



Data estimated by Lauer *et al.*

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[5] Emissions of International Shipping as Seen by Satellites, *ESA publications (2006), 628, pp 86.*

[6] *Multi Model Simulations of the Impact of International Shipping on Atmospheric Chemistry and Climate in 2000 and 2030.* Atmos. Chem. Phys. *(2007) 7, pp.757–780.*

[7] *Global Model Simulations of the Impact of Ocean-going Ships on Aerosols, Clouds and the Radiation Budget.* Atmos. Chem. Phys. *(2007) 7, pp.5061–5079.*

compared this with the reduction in radiative forcing resulting from a move from the base case scenario to a scenario which assumed the Kyoto protocol CO_2 targets were met. This resulted in a reduction in radiative forcing of 33.2 mW/m^2. Thus the global cooling effect directly generated by the current levels of SO_2 emissions from shipping is equivalent to more than a third of the cooling benefits generated by meeting the Kyoto protocol CO_2 targets. In other words, a global move to very low or zero sulphur levels in ship fuels would substantially negate the benefits of meeting the Kyoto Protocol from direct effects alone. If the magnitude of the additional indirect effects is confirmed, noting that some studies show this can be higher by an order of magnitude, this would become much more significant.

Lifetimes in the atmosphere

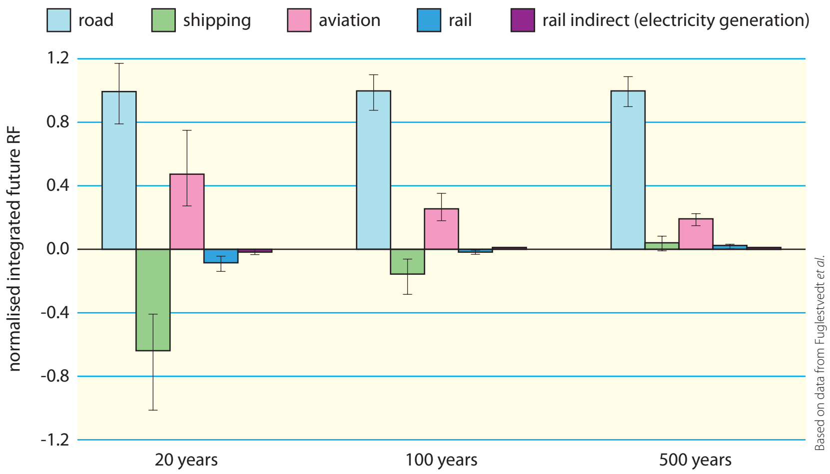
Comparing radiative forcing of different sources and compounds is often criticised as over-simplifying because of the different lifetimes of the agents in the atmosphere. Indeed, aerosol components have a short lifetime and do not accumulate in the atmosphere, so their effect decreases rapidly with time as soon as emissions decrease/cease. By contrast long lifetime agents (such as CO_2 and CH_4) are only slowly removed, thus they accumulate in time and their effects persist long after emissions have ceased.

Fuglestvedt *et al.*[8] examined the integrated impact of radiative forcing for different transport modes using the methodology of the *Fourth Assessment Report*. A pulse of a single year of emissions was simulated and the resulting radiative forcing integrated over a 20-, 100- and 500-year period. Figure 5 shows the cumulative results by mode of transport (normalised against road transport).

The effect of the short lifetime agents such as aerosols that produce negative forcing is seen to be strong over a time-scale of 20 years, diminishing to a low level over 100 years and vanishing in less than 500 years. Furthermore, shipping has a 'negative' climate footprint with present fuels.

Figure 5 Integrated radiative forcing of current emissions, by substance and transport sub-sector, over different time horizons

Integrated global mean net RF per sector due to 2000 transport emissions, normalised to the values for road transport for various time horizons (20, 100, 500 years). Uncertainty ranges are given as one standard deviation.



This means that any reduction or removal of SO_2 emissions has an almost immediate effect. The proposed global sulphur cap for marine fuel would essentially remove the current 'complete offsetting' of the 'warming signal' from CO_2 emissions from shipping, i.e. it would significantly increase the global positive forcing. All models predict this trend. There is disagreement on absolute effect, but even taking the lowest estimates from the MIT studies, effects on the scale of the Kyoto protocol ambitions are indicated.

More work in this important area is clearly needed to contribute to the development of holistic policies aimed at mitigating concerns over ship emissions. However, it is already clear that reducing the present sulphur content of marine fuels in sea areas where such emissions do not contribute significantly to problems of human health or the terrestrial environment (i.e. outside SECAs via a stringent sulphur cap) is certainly not precautionary from a climate change perspective. This may be another 'inconvenient truth' but, given what has been highlighted above, a review of the potential climate implications of the planned 2020 or 2025 imposition of a stringent global sulphur cap appears to be warranted.

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[8] Climate Forcing from the Transport Sectors. *Proceedings of the National Academy of Sciences of the USA, 2008, 105, no 2, pp.454–458.*