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Editorial

Emission control areas and their impact on maritime transport

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1. Background

The globalisation of trade which has occurred over the past few decades would not have been able to occur without the shipping industry. During this time, the price of shipping services has decreased, thanks to a combination of ever-larger ships and the development of intermodal supply chains. Demand for shipping has, therefore, increased dramatically since the mid-1990s. However, the corresponding increase in the supply of shipping has occurred without too much consideration of its environmental consequences. Although other modes of transport have come under considerable environmental scrutiny, shipping has largely escaped attention. This is partly due to the fact that regulations have been difficult to agree upon because of the international nature of the industry. However, it is also due to the fact that many of the environmental impacts take place at sea and so have fewer immediate *perceptible* impacts on the population.

Emissions from the shipping industry are closely correlated to its consumption of fuel. However, again, because of the international nature of shipping, even calculating the overall consumption of fuel is not without its difficulties. Historically, estimates have been derived from top-down analyses of fuel sales figures obtained from bunker suppliers. However, bottom-up approaches – based on the aggregation of the activity and characteristics of individual ships – have become more common over the past decade. This has occurred because there was a concern that results produced from the top-down approach were both systematically and significantly underestimating the global fuel consumption of ships. Bottom-up estimates of the global fuel consumption of ships vary according to the assumptions used and the modelling processes employed. However, as shown in Fig. 1, there is a general consensus that they yield higher fuel consumption estimates than the top-down approach. What is also clear from Fig. 1 is that, despite improvements in technology and shipping management, global fuel consumption has increased considerably over time (Corbett and Koehler, 2003, 2004; Endresen et al., 2004).

The vast majority (95%) of the world's shipping fleet runs on diesel. However, the diesel used in ships (usually referred to as bunker oil) is much lower quality than that used in road vehicles. Bunker fuel is much cheaper as it is virtually a waste product of the standard oil refining process. It is a cross between a solid and a liquid that is too thick for road vehicles – it is literally 'the bottom of the barrel'. Because of its low quality, even the most modern marine engines produce higher emissions per power output than regulated on-road diesel engines (Corbett and Farrell, 2002). As Fig. 2 implies, there exists a range of pollutants which are of more concern in relation to the shipping industry than to other modes of transport and of greater immediate concern than the CO_2 produced by the industry.

2. The regulation of sulphur emissions from ships

The International Maritime Organisation (IMO) has a long history of regulating ship pollution through its International Convention on the Prevention of Pollution from Ships (known as the MARPOL Convention). However, little attention was

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2007	Low bound	Best	High bound
Total fuel consumption	279	333	400

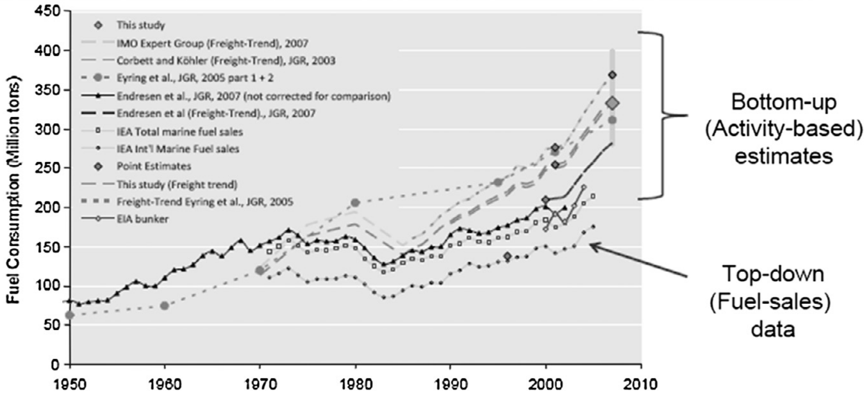

Fig. 1. World fleet fuel consumption. *Note*: the large diamond shows the International Maritime Organisation (IMO) consensus 'best estimate' and the whiskers the high and low bound estimates. *Source*: Buhaug et al. (2009).

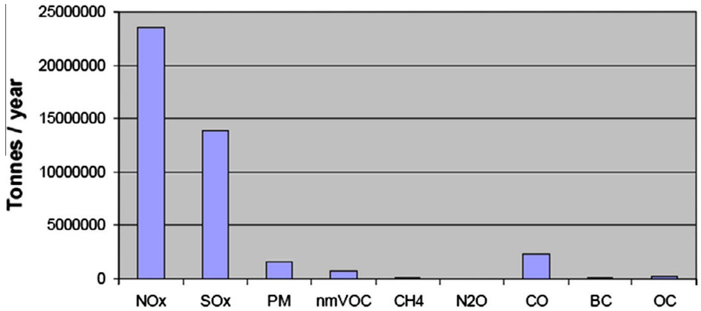

Fig. 2. Estimates of other emissions from shipping. *Source*: MARINTEK (2008).

paid to atmospheric emissions until the 1980s. The MARPOL Convention was updated by the "1997 Protocol" to include an Annex VI entitled "Regulations for the Prevention of Air Pollution from Ships". This annex prohibits the deliberate emission of ozone depleting substances in line with the Montreal Protocol and sets limits on the emissions of both NO_x and SO_x from ship exhausts.

In April 2008, the IMO's Marine Environmental Protection Committee (MEPC) agreed the latest revised version of MARPOL Annex VI, which sets the following global limits on the sulphur content of a ship's fuel: A reduction to 3.50% (35,000 ppm), effective 1 January 2012; a reduction to 0.50% (5000 ppm), effective 1 January 2020 but subject to a review to be completed no later than 2018. If this review is negative, the effective date defaults to 1 January 2025.

Two specific 'Emission Control Areas' (ECAs) have been defined – the Baltic Sea in May 2006 and the North Sea and English Channel in November 2007 – where more stringent caps on the sulphur content of fuel were established. These caps were a reduction to 1.00% (10,000 ppm) effective 1 March 2010 and a reduction to 0.10% (1000 ppm) effective 1 January 2015.

In addition to these new global and ECA caps, the new version of Annex VI reinforces the EU Marine Fuel Directive by specifying a sulphur cap of 0.10% at berth within the whole of the EU.[2] It also specified the future creation of North American and US Caribbean ECAs (for both SO_x and NO_x) in 2012 and 2014 respectively and specifically permitted the use of abatement technology to achieve the required reductions.

Towards the end of 2012/beginning of 2013 and in response to the IMO's 2008 revision of MARPOL Annex VI, the EU ratified amendments to Council Directive 1999/32/EC14 of 26 April 1999 relating to a reduction in the sulphur content of marine fuels.

With these amendments agreed, EU legislation now encompasses both the IMO's global SO_x regulations and its ECA limits. However, the EU regulations include the slightly more stringent variations; irrespective of the outcome of the proposed IMO review in 2018, a reduction to a cap of 0.50% (5000 ppm) sulphur content will be unilaterally implemented in the EU on 1

[2] There are certain exceptions to this.

January 2020 and also all passenger ships in the EU's non-ECA waters will have a maximum 1.5% sulphur content until that time.

Not only is the EU implementing an emission control area (ECA), but the US and Canada have also designated certain coastal areas as an ECA (US EPA, 2009). The application to the IMO Marine Environment Protection Committee (MEPC) adopted the changes to MARPOL Annex VI designating a North American ECA (DNV, 2012). The sulphur content of fuel oil used on board vessels operating inside the North American ECA must not exceed 1% as of 1 August 2012. The limits will be intensified as of 1 January 2015 when the sulphur limit should not exceed 0.1%. Different types of exhaust gas cleaning systems are permitted to be installed on board vessels as an equivalent to a fuel sulphur limit. As distinct from the EU's sulphur directive, the North American ECA also applies the more stringent ECA regulations on NO_x emissions as applicable solely to new ships.

The evolution and phasing-in of the various regulatory regimes are summarised in Fig. 3.

3. Content of the special issue

There are several strategic options available in order to address the upcoming regulations. In the first paper by Bengtsson, Magnusson, Fridell and Andersson, the authors address and examine three different strategic options for the upcoming emission control area (ECA) regulations and for nitrogen oxides (NO_x). The authors describe different possibilities related to abatement technologies as well as to change of fuels. The alternatives evaluated are: (1) heavy fuel oil (HFO) combined with Selective Catalytic Reduction (SCR) and an open loop sea water scrubber, (2) marine gas oil (MGO) combined with SCR and (3) liquefied natural gas (LNG). The alternatives are described and analysed using life cycle assessment (LCA). The results of the authors' analysis show that none of the alternatives will reduce the life cycle impact on climate change significantly compared to HFO. However, all alternatives will reduce the impact on particulate matter, photochemical ozone formation, acidification and terrestrial eutrophication potential in the life cycle.

The payback time of the different alternatives is a crucial factor in the decision-making of shipowners. When it comes to investment costs and using cost values from the Danish Maritime Authority, MGO in combination with SCR seems to be the least expensive option. It is difficult to estimate payback times due to specific circumstances; e.g., operational hours inside ECAs, the cost difference between different fuels, and the installation and operational costs for abatement technologies. The evaluation is further complicated by potential difficulties in estimating future fuel costs and the spread between different fuel prices.

Apart from the three alternatives for compliance, the assessment conducted also highlights the need for policy and regulatory measures; Firstly, related to the ammonia slip from the use of SCRs and, secondly, the methane slip from LNG engines. The paper also accounts for several cases where SCR technologies have been used in Swedish waters, greatly reducing the emissions of NO_x.

The second paper of the special issue by Jiang, Kronbak and Christensen examines the costs and benefits of different reduction measures in connection with the sulphur emission regulations and ECAs. The paper integrates the private abatement costs for shipowners and the social environmental benefits from emission control. The cost-benefit analysis is based on some key assumptions, mainly related to ship and route characteristics. For the purpose of the cost-benefit analysis, a container ship of 5000 TEUs (twenty-foot equivalent units) and the route between Gothenburg and Rotterdam have been chosen. Results show that scrubber technology is more efficient in reducing sulphur and particle emissions but generates slightly more CO_2 emissions. The environmental benefits of scrubbers on newbuilds and retrofits are about €2.5 million annually. The environmental benefit of switching to MGO is about €2.2 million annually. Given a price difference between HFO and MGO of about €190 per tonne, the MGO solution is most appealing from a cost perspective. The sensitivity analysis of the price difference between HFO and MGO, as compared to the net present value of MGO, illustrates that the price spread between marine gas oil and heavy fuel oil is a determining factor. The marine gas oil alternative has a higher net present value compared to the scrubber option when the price difference between HFO and MGO is less than €231 per tonne. Scrub-

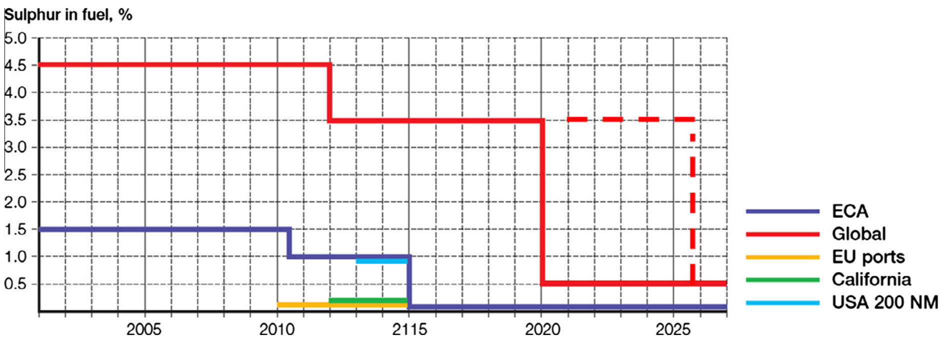

Fig. 3. The evolution of global and local sulphur legislation.

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bers are also a more attractive option for newbuilds compared to retrofits. According to the sensitivity analysis of a retrofit's remaining lifespan, an old ship is not suitable for a scrubber installation when its remaining lifespan is less than 4 years.

In the paper which follows, Schinas and Stefanakos examine and develop a multi-actor approach related to the financial assessment of different technologies for regulatory compliance with the MARPOL Annex VI sulphur regulations. To this end, they utilize the Analytical Network Process (ANP) and the Analytical Hierarchy Process (AHP).

They argue that their analysis of the problem on the basis of AHP offers a better understanding and insight from a decision making perspective. The proposed hierarchy exhibits the versatility of the approach; complicated hierarchies can be drafted, linguistic and crisp data can be integrated, and more alternatives can be considered. The hierarchies can evolve further to holarchies or hyperarchies depending on the needs of the problem. The solution of super-matrices can easily be handled by spreadsheets, as convergence occurs after only a few iterations. Moreover, the hierarchies and holarchies can incorporate well-established ship management data, thus enabling audit and control, as well as the usability and the applicability of the model among professionals. Hence, the developed multi-actor approach addresses the complex nature of the decision making which traditional NPV approaches fail to address.

In the fourth paper by Acciaro, an additional financial assessment method/model is provided, Real option analysis provides additional value compared to traditional discounted cash flow techniques by enabling account to be taken of the value of managerial flexibility – linked, for example, to the possibility of deferring an investment. This aspect of flexibility is especially important given the complexity and uncertainty of the regulatory framework related to environmental regulations and shipping, as well as the uncertainty and availability of technical alternatives for environmental compliance.

The paper applies real option analysis to a situation of retrofitting a handysize vessel with LNG. Depending on the remaining lifespan of the vessel, future technological developments and the change in fuel differentials, the model suggests that deferring investment in LNG to the near future might be an optimal strategy. Results show that there is a trade-off between low fuel prices and investments in LNG retrofit. The development of LNG as a marine fuel is determined to be critically dependent on the reduction in capital costs and ship retrofitting costs. Furthermore, this development is reliant on low prices for LNG fuels in the future. Policy makers can facilitate this development by providing support to advance technical knowledge, maintaining LNG prices at favourable levels and avoiding any ambiguity in regulation.

In the next paper, Doudnikoff and Lacoste examine the effect of reducing the speed of containerships in response to higher energy costs in sulphur emission control areas. This is an interesting market segment for such an analysis as there is a particularly close connection between energy use, speed and revenues in container shipping. Operators could consider reducing speed inside an ECA in order to save fuel that will become relatively more expensive. However, in order to maintain service and frequency, new ships might need to be added. Such strategies and behaviour implies that the required speed at sea outside an ECA will increase. The authors propose a cost model that estimates the cost-minimising combination of speeds inside and outside an ECA, as well as the resulting CO_2 emissions of the liner service.

When applying the model to representative liner services serving North Europe, the authors find that differentiating speed slightly decreases total costs and increases CO_2 emissions in a similar way. The results show, in most cases, a decrease in fuel cost of less than 3%. This reduction might not be sufficient to encourage speed differentiation strategies to be implemented. It should be noted, however, that the results are sensitive to the price of low-sulphur fuels, the part of the cycle which takes place within an ECA and the number of ships deployed in the service. In addition, the increase in CO_2 emissions when introducing speed differentiation is limited, but from a policy perspective, regulations that are designed to reduce SO_x emissions locally, may result in a slight increase in CO_2 emissions when considering the entire service.

In the sixth paper by Holmgren, Nikopoulou, Ramstedt and Woxenius, the issue of modal shift related to ECA regulations on sulphur emissions is considered. Voyage costs will increase as a result of the implementation of the revised MARPOL Annex VI regulations and this will likely lead to an increase in freight rates as shipping companies have difficulty absorbing the increase in costs. Within some shipping segments, an increase in constrained elasticity to freight rates may cause a modal shift. Other external factors can also exert some influence, resulting in either a strengthening or limiting of modal shift to road transport. An agent-based simulation (TAPAS model) is introduced in the paper in order to elaborate on modal shift effects. The main findings suggest that a modal backshift to road transport is unlikely to occur for the studied types and routes of transport, (i.e., shipments of relatively high-valued containerised goods from Lithuania to the British Midlands).

The authors emphasize that the ECA rules may become a challenge for some parts of the shipping market operating in the North and Baltic Sea and, therefore, may pose a certain risk in terms of reverse environmental effects. However, losses may be temporary and may only have an effect in the relatively short-term; until such time that the market responds adequately to the new operating conditions and companies, and their transport services, evolve to address this new regulatory context.

In the next paper, Panagakos, Stamatopoulou and Psaraftis examine the effect of designating the Mediterranean Sea as an ECA and consider some specific cases of consolidated cargo moving between Thessaloniki, Greece and the industrial hubs of northern Germany. For the analysis, a road-only option was assessed against a combined-transport route involving a ferry (Greece–Italy) and a truck-on-train (Italy–Austria) service.

The model applied takes the binomial logit form and takes into consideration transport cost and time as explanatory variables. Under certain assumptions comprising the 'basic scenario', the designation of the Mediterranean as an ECA will cause an increase in transport costs by about €6.95/tonne (equivalent to an increase of 1.9%). This cost increase will, according to the model, result in a modal shift of 5.2% in favour of the road-only route. Depending on the underlying assumptions, this might increase to about 17%.

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The modal shift contributes to significant improvements in all of the emissions examined (CO_2-eq, PM_{10}, NO_x and SO_2). This is explained by the longer distance of the combined-transport solution in comparison to the road-only route and the poor performance of the Ro-Pax vessels due to the need to maintain a relatively high speed. The railway involved in the combined-transport solution is the least environmentally damaging option, but constitutes only a comparatively small part of the route.

In the last paper of this special issue, Chang, Roh and Park assess noxious gases of vessel operation in a potential emission control area in the Port of Incheon, Korea. Specifically, the study measures the emissions of SO_2, NO_x and PM from vessel operations in the Port of Incheon. The paper adopts a bottom-up approach, based on the individual characteristics of vessels, using data on all vessels processed by the port in 2012. The results show that the activities at the port emitted 990 tons of SO_2, 1551 tons of NO_x and 142 tons of PM in 2012. International ferries, full container vessels, general cargo vessels, car carriers and chemical tankers accounted for 70–76% of the respective total emissions of noxious gases.

As a means of reducing emissions in a proposed emission control area in the Port of Incheon, speed reduction measures and the effects of reducing sulphur content with two options (1% and 0.1%) were analysed. The authors find that, within the range of speed reductions tested, noxious gas emissions could be reduced by about a third; The 1% rule could reduce the emissions by almost 70%, whereas the 0.1% rule could reduce the emissions by a remarkable 93%.

These results are particularly interesting given the geographical context where Asia holds most of the top ranking ports and has the most densely populated coastal areas in the world. However, no designated ECAs have been implemented in any country or region in Asia, despite the enormous anthropogenic pollution arising from the emission of noxious gases from seagoing vessels.

4. Conclusions

The first part of this special issue contains several assessments of abatement technologies and alternatives for complying with the regulations relating to emission control areas. Several researchers emphasize and illustrate the great environmental improvement potential of the different technologies and alternative fuels. Several authors also highlight the relatively low level of emission levels shipping is responsible for compared to other modes of transport.

The papers by Jiang, Kronbak, Christensen; Shinas and Stefanokos and Acciaro address the complicated issue, from the perspective of private operators, of deciding what measures and strategies to implement and the timing of such decisions. The outcomes of these authors' research shows that there are different possibilities and methods than can be applied in order to cope with the complexity inherent in the decision making process and that can provide some much-needed managerial flexibility.

From a modal shift perspective, given the cases analysed herein, modal shift effects resulting from the ECA regulations appear to be rather limited. The future imposition of more stringent limits on both SO_x and NO_x emissions, together with greater geographical applicability, will put energy use and other efficiency measures high on the agenda for shipping companies. This may result in the wider use of measures such as speed differentiation that, in turn, may enable shipping companies to better absorb the price changes arising from the ECA regulations.

The large socio-economic benefits of the ECA regulations, combined with the global challenges related to pollution in densely populated areas such as the Mediterranean and Asia, emphasize the importance of designating more regions as ECAs. Several contributors to this special issue have also highlighted the need for different policy and regulatory measures. The ammonia slip from the use of SCRs and the methane slip from LNG engines are some examples where supplementary regulation may be required. The papers included in this special issue provide important knowledge and understanding related to the ECA context, with the research presented constituting valuable inputs to both policy making and private sector decision-making.

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