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INTEGRATED ASSESSMENT OF AN EMISSION TRADING SCHEME TO REDUCE EMISSIONS FROM INTERNATIONAL SHIPPING AND THE RELATED ENVIRONMENTAL IMPACT OVER EUROPE

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Abstract: This paper assesses the use of an Emission Trading Scheme (ETS) for the year 2020 to reduce the emissions from international ships entering European Community ports. Additional costs and benefits of including the maritime sector into a land-based ETS for NO_x and SO_2 are quantified.

Key words: *maritime; emission trading, integrated impact assessment.*

INTRODUCTION

Shipping transports the majority of goods traded internationally and although it is acknowledged as being the most efficient and the most environmentally friendly mode of transport it is also an important contributor to anthropogenic emissions. An integrated assessment is made of the use of an Emission Trading Scheme (ETS) for the year 2020 to reduce the emissions from international ships entering European Community ports.

DEVELOPMENT OF FUTURE MARITIME EMISSIONS DATABASE

We used EX-TREMIS, EUROSTAT databases and emission factors (from the EMMOSS study) to construct a spatially explicit database projections for 2016, 2020, and 2030 that account for activity data and port callings. The database distinguishes between 7 vessel types and 5 size classes. The emission baseline takes into account several recently adopted policy measures. The most recent ones being the additional measures to reduce NO_x and SO_2 from maritime emissions according to the amendments of October 2008 to MARPOL ANNEX VI:

- Sulphur cap on all fuels of 3.5% in 2012
- Progressive reduction of Sulphur content to 0.5% in 2020 (after review in 2018)
- SECA: 1% Sulphur cap starting 01/03/2010 and 0.1% in 2015
- NO_x: Tier II: maximum 14.4 g/kWh in 2011 (for new ships)
- NO_x: Tier III: maximum 3.4 g/kWh in 2016 (for new ships), in Emission Control Areas (ECA).

The most important conclusions are as follows:

- Although fuel consumption by shipping is projected to increase from nearly 50 MTons (2016) to 63 MTons (2030), as a consequence of transport demand (27% increase in 2030 compared to 2016), NO_x-emissions are more or less constant 3MTons (2016) to 3.3 MTons (2030) (or 4% increase) and SO_2-emissions show a strong decline 1 MTons (2016) to 0.479 MTons (2030) (or 68% decrease). This is the direct consequence of the recently adopted IMO legislation on NO_x- and SO_2-emissions.
- Container vessels are the largest polluters (1 MTons NO_x in 2020), followed by tankers (nearly 0.7 MTons NO_x in 2020) and then bulk container ships (nearly 0.62 MTons NO_x in 2020) – with the remainder being under (0.4 MTons NO_x in 2020).
- All vessels show a large decrease in SO_2 emissions between 2016 and 2020 due to the new IMO regulations setting the upper bound of Sulphur content of maritime fuel to 0.5% (container ships are expected to fall from 0.48 MTons in 2016 to 0.12 MTons in 2020).
- 70% of NO_x emissions and 85% of SO_2 emissions occur outside the EU ports
- The most important ports are in N-W Europe and the busiest shipping lane is the one taking ships from the N-W European ports to the Suez canal.
- The validation of the developed database by comparing data with the TREMOVE model and IIASA data shows in general a good match. Although in Greece the port emissions are higher by a factor of 2.4 – due to the fact that RORO vessels in this region are much smaller than the RORO vessels in N-W Europe.

TECHNOLOGIES TO REDUCE MARITIME EMISSIONS

An extensive literature review and expert consultation was carried out to investigate the appropriateness of existing and potential technologies to reduce NO_x and SO_2 emissions from shipping. The most interesting technologies analysed further were: NO_x abatement - Direct water injection (DWI), Humid air intake (HAI), Water emulsion, Selective catalytic reduction (SCR), Liquid Natural Gas (LNG), Shore side electricity (SSE) and Kite sails; SO_2 abatement - Low sulphur fuel (LSF), Sea water scrubbing(SWS) and Kite sails. The abatement cost curves are developed based on "conservative" and "optimistic" scenarios to explore the uncertainty of aggregated abatement cost curves for 2016, 2020 and 2030.

ESTIMATED COSTS TO REDUCE MARITIME EMISSIONS

On the basis of the emissions projections and marginal abatement cost curves for the maritime sector a land based ETS including maritime emissions could have potential for NO_x because :

- 2020 projections for maritime NO_x emissions in European seas (3251 KTons) are 20% greater than the land based NO_x IPPC emissions (2714 KTons).
- The 12 nm zone + ports maritime emissions are approximately 25% of land based NO_x IPPC emissions

- At a reduction cost of 2000 EUR/ton, the reduction potential for European Seas (based on the conservative scenario Scen 1 in 2020) is around 1000 KTons (900 KTons (non ECA zones) and 100 KTons (ECA zones)), at the same level one would expect about 150 KTons to be reduced in the 12nm zone and ports (118 KTons (non ECA zones) and 40 KTons (ECA zones)).
- The cheap reduction potential is growing over time with ever more TIER III compliant ships entering the fleet. By 2020 emission reductions of up to 1075 KTons out of the projected 3250 KTons will be feasible mostly by using SCR in non ECA areas as well.

On the basis of the emissions projections and marginal abatement cost curves for the maritime sector a land based ETS including maritime emissions would have little potential for SO_2 because:

- 2020 projections for maritime SO_2 emissions in European seas (412 KTons) are only 15% of land based SO_2 IPPC emissions (2755 KTons).
- At a reduction cost of 10000 EUR/ton, the reduction potential for European Seas (based on the conservative scenario Scen 1 in 2020) is around 330 KTons (300 KTons (non ECA zones) and 30 KTons (ECA zones)), at the same level one would expect about 40 KTons to be reduced in the 12nm zone and ports (30 KTons (non ECA zones) and 10 KTons (ECA zones)).
- The reduction potential for SO_2 in the maritime sector is therefore small and expensive from 2020 onwards due to the stricter IMO regulations.

INFORMATION FROM THE LAND BASED ETS

A parallel project investigating the possibilities to develop a land based ETS for NO_x and SO_2 provided aggregated information from four trading scenarios with increasing ambition levels.

- BAC-High: a low ambitions scenario resulting in a trade price of 0 € for NO_x and 233€ for SO_2
- CAT-High: a somewhat higher ambition scenario, resulting in a trade price of € 442 for NO_x and € 774 for SO_2
- BAC-Low: a very ambitious scenario resulting in a trading price of €3397 for NO_x and € 93276 for SO_2
- CAT-Low: an extremely ambitious scenario resulting in a trade price of € 19377 for NO_x and €83518 for SO_2

Besides baseline emissions for 2020 the following information was delivered for each scenario:

- NO_x and SO_2 emission reductions for each sector/MS combination.
- The yearly cost involved for each sector/MS combination for reducing NO_x and SO_2 emissions up to the scenario level. (level: MS, sector, pollutant, scenario)
- The current trading price per scenario

Marginal abatement cost curves were constructed under the form of four parabolic (quadratic) functions, and used as input to the Emission Trading Tool.

ANALYSIS EMISSION REDUCTION COST CURVES AND THE SETTING UP OF MODELLING SCENARIOS

On the basis of aggregated NO_x marginal abatement cost curves for land based (LB), land based + maritime emissions (12nm zone + ports) and land based + maritime emissions (EU waters) for the conservative (Scen1) and optimistic (Scen2) scenarios, we see that between a trading price of 1K €/Ton and 3.5 K €/Ton the potential for reducing more NO_x emissions is higher for the maritime sector (especially emissions in the EU waters) (Figure 1). The optimistic scenario has a higher potential still than the conservative scenario – but we adopt the conservative scenario as the optimistic scenario is very uncertain. On the basis of aggregated SO_2 marginal abatement cost curves for land based (LB), and land based + maritime emissions (EU waters) for the conservative (Scen1) there is very limited reduction potential for SO_2. Maritime emissions in 2020 - the limited reduction potential that does exist is only at a price higher than 4k€/ton. This is a result of the strengthening of the environmental legislation for SO_2 emissions in the maritime sector which will come into force after 2016. In fact the remaining maritime emissions even at higher trading prices such as 10 k€/ton will be very low compared to land based emissions and so the opportunities to reduce SO_2 further will be very limited. On the basis of this we decided not to include the maritime sector in a land based ETS.

On the basis of the aggregated marginal abatement cost curves for land based emissions, maritime emissions for 12nm zone + ports and maritime emissions from EU waters – we could set up different emission trading scenarios. After consultation with DG Environment the following trading prices for NO_x and SO_2 were used:

- NO_x trading price 241 €/ton, SO_2 trading price 256€/ton ("Low")
- NO_x trading price 1194 €/ton, SO_2 trading price 2913 €/ton ("High")

We consider two fixed price scenarios and fixed volume scenarios. In the fixed price scenarios we keep the trading price at the level of a corresponding IPPC land base scenario. Including emissions of the maritime sector results in additional emissions reduction of maritime emissions and the level of land based IPPC emissions remains the same.

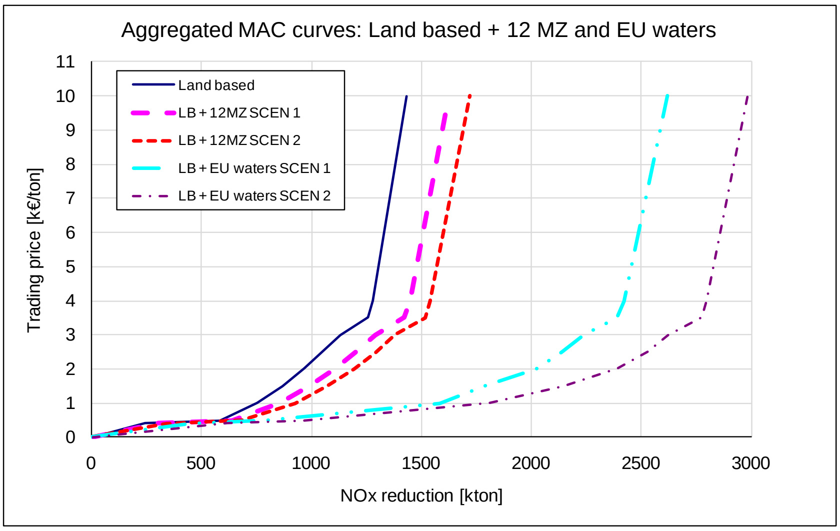

Figure 16. Aggregated MAC curves for land based and Maritime NO_x emissions.

Fixed volume scenarios are also relative to a land based scenario. In this case we lower the trading price up to the level that the global emission reduction (land based + maritime) is similar to reduction in the corresponding land based scenario. This means that the maritime sector takes over a part of the emissions reduction of land based sources.

- Baseline scenario (S1) – is the reference scenario corresponding to implemented legislation and policy for 2020.
- Scenario 2A (S2A) – is the IPPC only ETS with a fixed low NO_x trading price (241 €/Ton).
- Scenario 2B (S2B) – is the IPPC + EU wide maritime emissions ETS with a fixed low NO_x trading price (241 €/Ton).
- Scenario 2C (S2C) – is the IPPC + Maritime emissions from 12 nm zone and ports ETS with a fixed low NO_x trading price (241 €/Ton).
- Scenario 3A (S3A) – is the IPPC only ETS with a fixed high NO_x trading price (1194 €/Ton).
- Scenario 3B (S3B) – is the IPPC + EU wide maritime emissions ETS with a fixed high NO_x trading price (1194 €/Ton).
- Scenario 3C (S3C) – is the IPPC + Maritime emissions from 12 nm zone and ports ETS with a fixed high NO_x trading price (1194 €/Ton).
- Scenario 4B (S4B) - is the IPPC + EU wide maritime emissions ETS fixed volume scenario (to 2a) whereby the reduction volume of scenario S2a is realised by land bases sources and all maritime sources in EU waters. This allows lowering the trading price, compared to scenario S2a.
- Scenario 4C (S4C) - is the IPPC + Maritime emissions from 12 nm zone and ports ETS fixed volume scenario (to S3A) whereby the reduction volume of scenario S3A is realised by land bases sources and maritime sources in EU 12nm zone and ports. This allows lowering the trading price, compared to scenario S3A.

OUTCOME OF THE EMISSIONS TRADING TOOL

In Scenario 2 total NO_x emissions are reduced by between 5% and 11% only. One cannot expect a significant environmental benefit from such small reductions. Moreover, a trading price of € 241 €/ton is very low compared to marginal reduction costs listed in literature or resulting from the GAINS model. In Scenario 3, however, total NO_x emissions are reduced by between 30% and 61%. From these scenarios one can expect significant environmental benefits. The fixed volume scenarios S4B and S4C are able to spread some of the land based emission reductions to the maritime sector, which results in an overall reduction in the investments costs in the abatement technology – as abatement technologies for the maritime sector are cheaper than the IPPC sector. These scenarios have been chosen for analytical reasons, allowing to analyse the effects of a potential shift of land based to maritime reductions. Scenarios 2B and 3B results in maritime emissions being similar to the IPPC sector. If the maritime trading is limited to ports and 12 miles zone, we obtain an additional reduction of 40% in scenario 2 and 14 % in scenario 3. However, reductions, both for land based and maritime emissions are limited in scenario 2. We therefore believe that scenarios with a high trading price (S3 and S4c) are most promising for further analysis.

DISAGGREGATION OF EMISSIONS

Emissions were created with a GIS based database, in which emission inventories, spatial proxy data and a BelEUROS grid description were combined in order to disaggregate emissions from the chosen emission inventory on the BelEUROS grid, based on the geographical patterns revealed by the proxy data. In the database, land based and maritime emissions were treated separately. Moreover, land based emissions were split in emissions stemming from point, line, and area sources. Maritime emissions were split into emissions stemming from ships and from ports.

ATMOSPHERIC DISPERSION MODELLING

BelEUROS is an air pollution dispersion model specifically developed for policy support and scenario analysis. As such, it is a well suited tool to model the impact of various emission trading scenarios for different time horizons. The model calculates hourly concentration fields in combination with dry and wet depositions to the ground and seas. The chemical module of BelEUROS takes into account more than 200 chemical species but output is generated for the more common species such as

NO, NO_2, SO_2, NH_3, PM_{10}, $PM_{2.5}$, O_3, nitrates, sulphates, ammonium and primary species of fine particulate matter. In this study a grid refinement to three levels was applied for the BelEUROS model resulting in a longitude–latitude resolution of 0.1375 x 0.1375° (approximately 15 km x 15 km). This results in 208 grid cells in x-direction and 220 grid cells in y-direction, thus in total 45,760 grid cells in the model domain. Concentration maps were made for the components NO_2, O_3, SO_2, $PM_{2.5}$ and PM_{10} with a resolution of 15 x 15 km. Deposition maps showing the sum of dry and wet deposition were made for the components NH_3, NO_2 and SO_2 with a resolution of 60 x60 km.

IMPACT ASSESSMENT

For an integrated environmental assessment of the health and the environmental benefits of including the maritime sector into a land based ETS for NO_x and SO_2 use is usually made of a basket of indicators that cover different health and ecosystem impacts. The indicators that we have selected to be part of this basket of indicators include:

- Indicator 1: Years of Lost Life (YOLLad), where YOLLad is life expectancy reduction for adults (> 30 years) due to long-term exposure to $PM_{2.5}$;
- Indicator 2: Years of Lost Life (YOLLinf), where YOLLinf is increased mortality risks for infants due to exposure to PM_{10};
- Indicator 3: Valuation of public health damages of $PM_{2.5}$ in MEuros per year based on valuation (low estimate) of indicator 1 (YOLLad) and accounting for additional morbidity impacts;
- Indicator 4: Valuation of public health damages of PM_{10} damages in MEuros per year based on valuation (high estimate) of indicator 2 (YOLLinf) and accounting for additional morbidity impacts;
- Indicator 5: SOMO35, where SOMO35 is health damage due to ozone exposure in MEuros per year;
- Indicator 6: Change in degree of ecosystem eutrophication, based on the exceedance of nutrient critical loads in kg N/ha.
- Indicator 7: Change in the area of ecosystem acidification, based on the exceedance of acidification critical loads

Instead of calculating all indicators for all scenarios we have taken a step-wise approach to select the most relevant scenarios for an integrated assessment:

- Step 1: Compare Scenarios 2 and 3 to the Basecase scenario for IPPC only and IPPC + maritime emissions from EU waters in terms of the valuation of the YOLLadult indicator (indicator 3).
- Step 2: Within Scenario 2 or 3 compare the sub scenario IPPC + maritime emissions from EU waters or IPPC + EU ports & 12 nautical mile zones in terms of the valuation of the YOLLadult indicator (indicator 3).
- Step 3: Use the defined basket of the indicators to assess the most interesting scenario that involves the maritime sector in a land based ETS resulting from Step 2 – and compare with the most relevant IPPC only ETS scenario.

Step 1 and Step 2 involves the calculation of the net monetised benefits - calculated as the total reduction in external costs minus the yearly costs of NO_x and SO_2 reduction. The net monetised benefit is taken to be a welfare indicator for the scenarios. Not considering uncertainty in the evaluation of costs and benefits, the interpretation of the net monetised benefit is straightforward, the higher the better. When comparing scenarios we can also look at the incremental benefits and express these per unit of additional reduction. If the classical micro-economic paradigm applies - increasing marginal reductions costs and decreasing marginal benefits - a positive result indicates that the optimal welfare is not yet reached, i.e. that reducing further would increase welfare. Any negative figures would indicate that the reduction is too stringent. When considering uncertainty in quantifying costs and benefits, then high per unit additional monetised benefits indicates a high degree of certainty of opportunities to increase welfare.

Step1 indicated that Scenario 3B (18773 M€) has almost five times more net benefits compared to Scenario 2B (3928 M€). On the basis of the external costs and map comparisons we discarded the S2 scenarios (i.e. S2A, S2B) from further impact assessment analysis.

Comparison of Scenarios 3B and 3C demonstrate that the benefits of reducing emissions in ports and 12nmz largely exceeds the benefits of reducing maritime emissions. This can be seen from comparing the per unit of reduction additional monetized benefit. For scenario 3C, this amounts to 14.9 M€/KTon whereas for scenario 3B we obtain 4.3 M€/KTon We also considered Scenario 4C which is an alternative to Scenario 3C whereby the reduction volume of Scenario 3A is realized by land based sources and maritime sources in the EU 12nm zones and EU Ports. This results in a lowering of the NO_x trading price from 1194 to 827 €/Ton. The relative difference maps between Scenario 4C and Scenario 3A indicate that this fixed volume scenario results in a relatively small % increase (pink shading) in NO_2 and PM2.5 concentrations over land and a relatively large % decrease (dark blue shading) in NO_2 and PM2.5 concentrations in the 12nm zones and the coastal regions. For this example the UK shows a relatively greater increase in NO_2 and PM2.5 concentrations than mainland Europe because in UK there is a relatively high reduction potential between the trading prices of scenario S3A and S4C, meaning that for this scenario more than 25% of the maritime NO_x emissions are transferred to the UK.

On the basis of Steps 1 and 2 we therefore carried out an integrated environmental assessment of Scenario 3C - Land based IPPC + Maritime trading from 12 nm zone + ports, high trading price fixed at 1194 €/Ton. The spatial distribution of the YOLLad and YOLLinf indicators for Scenario 3C shows that concentrations of $PM_{2.5}$ and PM_{10} are highest in the known air quality hotspots across Europe (the Low Countries, northern Italy and other major urban areas). The relative difference maps comparing the results of 3C and 3A for YOLLad on inspection shows that the inclusion of the maritime sector in a land based ETS has the most impact in northern Europe, in particular over the land areas adjacent to the Baltic Sea and North Sea. This is not surprising because the largest amounts of maritime emissions occurring within the 12 nm zone + ports are emitted in these regions. One would have expected a greater impact in coastal areas close to the Straits of Gibraltar, however the BelEUROS grid does not extend so far south. The positive impacts in terms of Scenario 3C compared to Scenario 3A for decreases in damage caused by ozone concentrations (Indicator 5) and the degree of eutrophication (Indicator 6) and acidification (Indicator 7) across the EC are rather limited.

Table 8. External cost assessment of ETS Scenarios 3A, 3B and 3C based on the output of Emission Trading Tool (Chapter 6) and the valuation of YOLLadult (Indicator 3)

	Scenario description	Total NO_x emissions reduction (KTon)	Total SO_2 emissions reduction (KTon)	Yearly costs in abatement technology (capital and recurrent) for SO_2 (M€)	Yearly costs in abatement technology (capital and recurrent) for NO_x (M€)	NO_x emissions reduction cost (€/Ton)	Total external costs of YOLLadult (M€)	Reduction of external costs comp-ared to S1 (M€)	Net monetised benefits of ETS scenarios (M€)	Additional monetised benefits of including maritime (M€/KTon)	Maritime NOx emissions reduction (KTon)
		A	B	C	D	E	F	G	H	I	J
S1	**Basecase**						354275				
S3a	**Land based IPPC only emissions - high trading price**	803	1275	686	379	472	338113	16162	15097		0
S3b	**Land based IPPC + All EU Maritime emissions - high trading price**	1660	1275	686	927	559	333889	20386	18773	4.3	857
S3c	**Land based IPPC + EU ports & 12 nmz emissions - high trading price**	916	1275	686	427	466	336379	17896	16783	14.9	113
S4C	**Land based IPPC + ports + 12nmz, reduction S3A**	803	240	686	314	391	338416	15859	15545	4.6	97

CONCLUSIONS

We conclude therefore that there is an additional benefit of including the maritime sector in a land based ETS, but only if the trading price is sufficiently high. Scenario 3 which sets the NO_x trading price at 1194 Euro/Ton, results in significant improvements in terms of the valuation of the Years of Lost Life for adults (YOLLad) indicator – however we view that it would be more effective to restrict the maritime emissions to the 12 nm zone + ports zones in the EU because:

1) the legal analysis indicates all vessels (EC and non-EC) can be required to join an ETS regime in ports (+ internal waters) and territorial seas (i.e. within the 12 nm zone). This means that a cap on maritime emissions can be imposed and the scheme is not voluntary.
2) the effectiveness of emissions abated in the 12 nm zone + ports zones, although much lower in volume, are more effective in terms of reducing environmental impacts than emissions abated in all EU waters.

One practical problem that would have to be resolved is that due to the fact that foreign ships enjoy the "right of innocent passage" in territorial seas no construction, design, equipment and manning (CDEM measures), going beyond the generally accepted international rules and standards, may be involved. To ensure that an ETS is robust and secure requires a full proof monitoring and verification scheme – this means that ships would need to install equipment such as the on-line Continuous Emission Monitoring System (CEMS), which is currently not a standard equipment for all ships.

For this reason the European Commission or Member States might want to consider alternative market based instruments or measures to reduce NO_x emissions from ships, such as differentiated kilometre charges, taxation, port dues and subsidies.

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