MARITIME EMISSIONS: MODELING AND MEASURING POLICY EFFECTS.

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ABSTRACT

Maritime emissions have long time been a low priority issue for policy makers. However, maritime emissions will be included in the European National Emission Ceilings (NEC) and as maritime transport is increasing rapidly, its share in emissions is thought to become more significant.
So maritime emissions are becoming more important for national and international policy makers, and pressure is rising to reduce emissions. As such, policy makers need a tool to estimate current emissions and to asses the impact of policy measures on emissions, especially with respect to harbor emissions.
To this end, we have constructed an emission model to calculate and distribute maritime emissions geographically. Furthermore, we modeled future emissions starting from a traffic prognosis, taking into account fleet renewal, technological improvement, existing legislation, and increase (or decrease) of ship size.
For Belgian maritime emissions, we found that total maritime emissions have been increasing slowly from 1990 to 2005, yet slower then traffic, e.g., NO_x emissions increased 23% while traffic increased 36%. We furthermore found that more than half of all emissions are in-port emissions.
With the model we calculated the effect of two policy measures: first, MARPOL annex VI concerning NO_x emission standards, and second, European guideline 2005/33/EC concerning the sulphur content of maritime fuel. We found that the MARPOL annex had no significant impact on NO_x emissions, while the European guideline will decrease emissions of SO_2 in harbors to 36% in 2010 compared to 1990.
Emissions of maritime transport are increasing rapidly. In a business-as-usual (BAU) scenario, emissions per traffic will decrease slowly, although measures to reduce emissions are available (shore-side electricity, exhaust aftertreatment, fuel quality,…) and can reduce emissions significantly.

KEYWORDS: Maritime transport, emissions, model, policy, NOx, SO2

INTRODUCTION

Emissions of maritime transport are in many ways very different to emission of other transport modes. First, the international profile of maritime transport causes that various policy makers can have an impact on different aspects of maritime transport. This can be seen in the different jurisdiction of the International Maritime Organization (IMO), the European Commission and national governments. The international aspect of maritime transport has also been cause of discussion concerning the allocation of the emissions, especially with the introduction of the National Emission Ceilings (NEC). Secondly, due to the large scale of maritime transport, as compared to other modes, large combustion engines are often used, allowing for other options and solutions for emission control to become feasible.

Transport & Mobility Leuven constructed an activity based model for the Flemish government to calculate the emissions of maritime transport on Flemish territory; namely the Flemish ports and the Belgian continental shelf. This is in fact equal to the Belgian maritime emissions. This model has been used to calculate the past, current and future emissions of all maritime transport, taken into account all current (e.g. MARPOL annex VI) and planned (e.g. low sulphur fuel in harbors) legislation.

In this paper we will first elaborate on the methodological aspects of the model after which we present the results for Flanders, as a time series of maritime emissions from 1990 to 2030. Also, we evaluate the effect of the agreed legislation. In conclusion we assess the impact of some possible new measures on maritime emissions.

THE MODEL[1]

The model is in principle based on the methodology used by the ENTEC study[2] and can in general be summarized by three simple formulas:

1. Energy use (kWh) = time (h) x installed engine power (kW) x engine load factor (%) x number of ships
2. Fuel use (kg) = *energy use (kWh)* / engine efficiency (%) / energy content of the fuel (kWh/kg)
3. Emissions (kg) = *fuel use (kg)* x emission factor (kg/kg) x correction factor (-)

The formula for the calculation of energy use is very specific for maritime emission modeling. The factor 'time' can be derived from various vessel tracking information systems. The factor 'installed engine power' is well documented in vessel databases. For the model we used a correlation algorithm between the gross tonnage of the vessel and installed power, per vessel type, categorized in main and auxiliary power.[3] The factor 'engine load factor' is typical for various activities. In the model we distinguish the activities full speed, reduced speed, maneuvering, in lock and at berth. The engine load factors are specific for each vessel type, e.g. roro-vessels use relatively high amounts of auxiliary power for ventilation purposes. Also, during maneuvering, auxiliary power use can be high due to auxiliary propulsion and navigation units. The other formulas to calculate fuel consumption and emissions are straightforward. The introduction of a correction factor is necessary to take into account the change in emission factor at low engine load factors. As expected, the emission factor particularly for CO and VOC, increases when engine load factor are below 50%.

Compared to the ENTEC study, the model we constructed for Flanders uses other sources and different detail levels for several parameters. In the ENTEC study, activity is based on the database of Lloyds Marine Intelligence Unit, while for this model detailed data concerning ship movements where extracted from port information systems and the information system for the river Schelde, called IVS-SRK. From this data a detailed vessel characteristics database and vessel movement database was constructed specifically for the Belgian seaports. Emission factors were taken from the Dutch EMS protocol.[4]

Some specific features of this model include the detailed calculation methodology for in port emissions, due to excellent data availability from the information systems. Time spent due to maneuvering, in-lock time and time at berth were estimated for 11 vessel types, 5 length classes, separately for every port, thus implicitly taking into account port infrastructure features.

Prognoses of emissions were estimated from port traffic prognosis, based on earlier studies, MOPSEA[5] and ECSA[6] and expert opinion, taking into account the evolution of vessel size, age-distribution and taking into account the effect of several agreed policy measures. The evolution of vessel size was estimated on detailed level, e.g. the world container fleet is rapidly increasing in size, yet this evolution cannot per se be extrapolated for individual ports due to infrastructure limitations and port product specialization. Vessel size increase (or decrease) is thus estimated for every port and vessel type individually. We used this estimated vessel size growth figure in an algorithm to estimate the vessel size distribution, in 5 length classes.

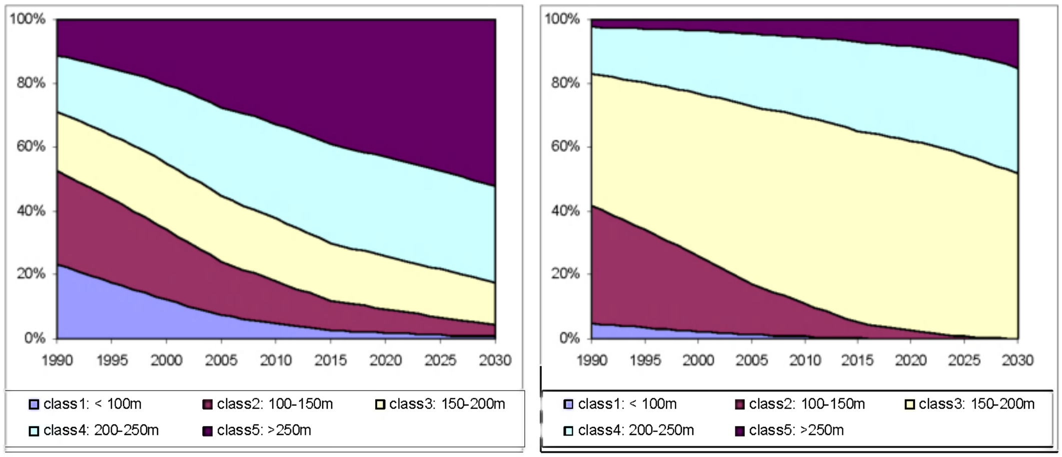

Figure 1: examples of evolution of vessel size. Left: containerships in Antwerp, right: roro-ships in Zeebrugge.

Figure 1 shows the share of vessels per length class for every year, from 1990 to 2030. The left chart reflects the evolution for containerships in Antwerp. The worldwide trend of increased vessel size can clearly be seen here. The right chart shows the evolution of roro-ships in Zeebrugge. The evolution of increased size is also present here, although vessels remain relatively small, as compared to containerships in Antwerp.

RESULTS

With the model, we calculated the emissions for 2005 and estimated the future and past emissions in a time series from 1990 to 2030 with 5 year intervals. In absolute figures an estimated 1 Mt CO_2 was produced by maritime transport in Flanders in 2005. For NO_x and SO_2 this is respectively 23 kt and 13 kt. As can be seen in Figure 2 the emissions are evenly distributed over the vessel types, with 2 exceptions: roro and container, as could be expected due to their importance in total traffic. Variations of share in total emissions between the pollutants indicate typical features of the vessel types. E.g. containerships have a relatively high share SO_2 as compared to other pollutants, which is due to the larger average size of containerships thus equipped with large engines, allowing more often the use of (high sulphur) heavy fuel. High shares of CO and VOC indicate an aging fleet of this specific vessel type (e.g. roro and general cargo).

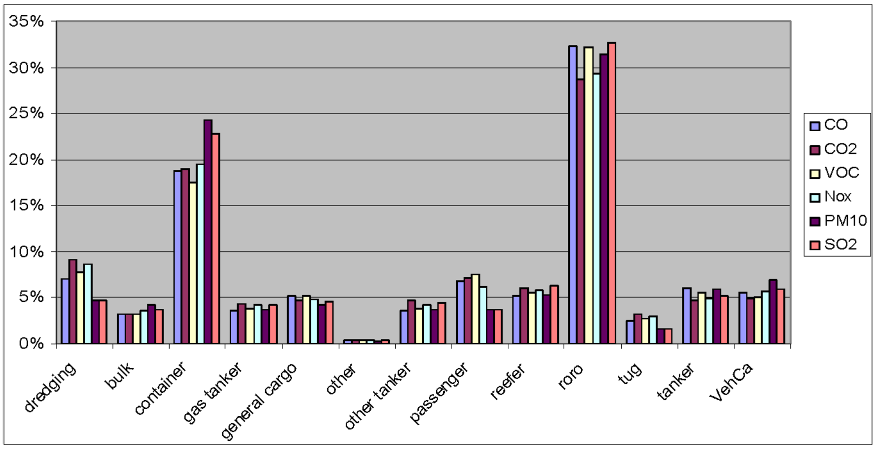

Figure 2: Share of maritime emissions per vessel type per pollutant for 2005 in Flanders

The case of Flemish maritime emissions is very specific due to the presence of several important ports (Antwerp, Zeebrugge, and Gent) and the relatively small area of territorial sea. As a result, we found that an estimated 50-60% of the emission is produced in ports, depending on the pollutant. Moreover, since in port, during maneuvering or at berth, the main engines are often turned off and extra auxiliary power is needed for navigating, we found that 35-55% of all emissions are produced by auxiliary engines.

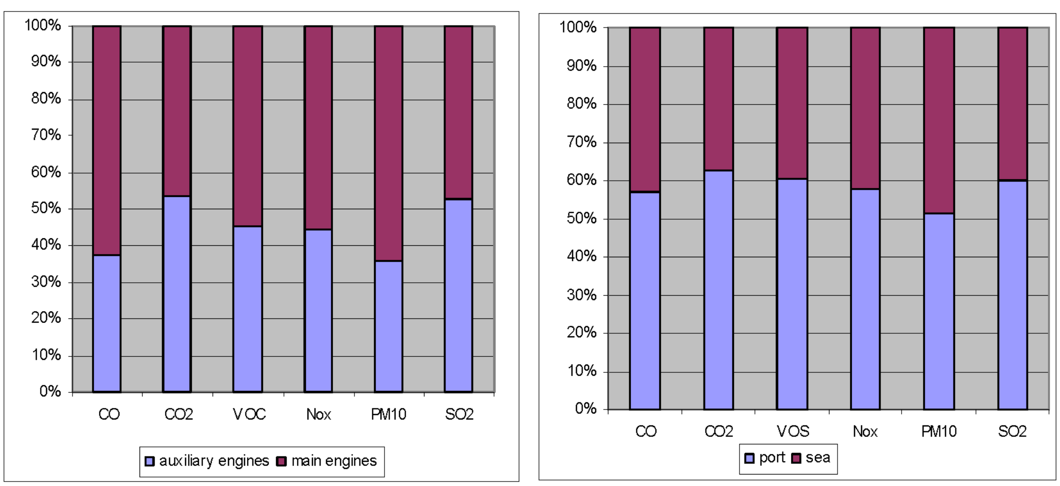

Figure 3: Share of emission according to source, auxiliary engines or main engines (left) and location, in port or at sea (right)

When focusing on the evolution of maritime emissions, we can asses the effect of some agreed policy measures. We measured the effects of 3 measures:

- The MARPOL annex VI, imposed by the IMO, concerning emission standards for NO_x which came into force 19/05/2005.
- The North Sea SO_2 Emission Control Area (SECA), allowing a maximum value of 1.5% sulphur content for all marine fuels, also imposed by the IMO. This measure came into force 11/08/2007
- The European directive concerning marine fuels allows a maximum value of 0.1% sulphur content of fuels used by all vessels at berth. This measure will come into force 01/01/2010

In Figure 4 is shown that as maritime traffic is increasing, emissions of most pollutants are also increasing, albeit less then traffic. Apart from the imposed measures, this indicates a generic improvement of specific emissions driven by an ongoing improvement of engine efficiency in the maritime sector. This can clearly be seen in the reduction of the CO2, CO and VOC specific emissions, while no legislation is regulating the emissions of these pollutants.

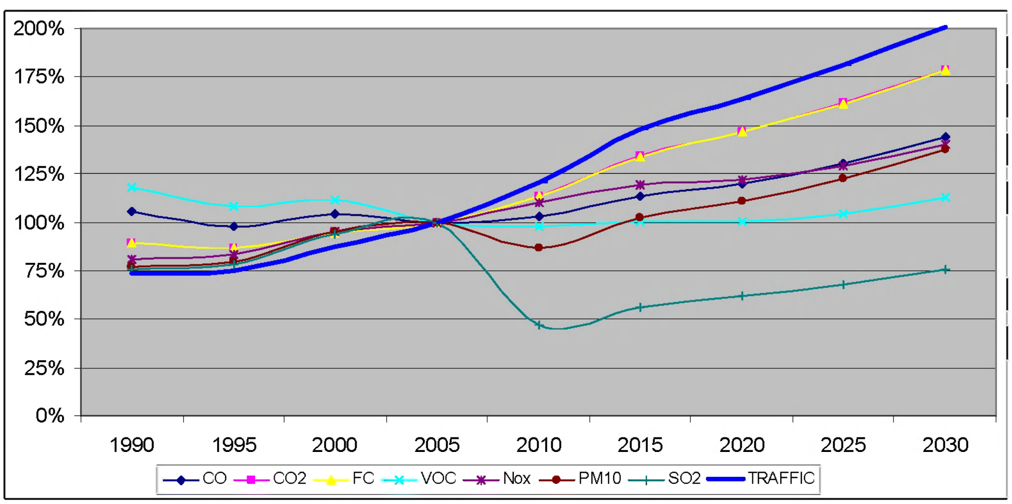

Figure 4: Evolution of maritime emissions in Flanders from 1990 to 2030, with 2005 as reference year

When we investigate the effect of the MARPOL annex VI, we can observe an increase of the NO_x emissions, yet an improvement of the specific emissions is clear: while traffic doubles in 2030 compared to 2005, NO_x emissions increase only 40%. However, this steady improvement has also been going on in the period 1990 to 2005, when traffic increased 36%, NO_x emissions increased only 23%, without regulations. Moreover, this trend is also present for the other pollutants. It is unclear if this trend would have persisted in the period 2005 to 2030 if the measure was not introduced; still, the measure proves to be moderately ambitious when taking into account the potential of

NO_x emission reduction in maritime transport, especially compared to other transport modes.

The measures to reduce SO_2 emission both focus on the sulphur content of the fuel. The effect is clear: emissions of SO_2 fall to 75% in 2030 compared to the level in 2005. When looking at the results in detail, the impact of both measures is evenly distributed. While the first measure, allowing a maximum of 1.5% sulphur content, reduces overall SO_2 emission, the second measure affects only in port emissions. As fuel sulphur levels also influence PM10 emissions, a small reduction of PM10 emissions is also observed. Without the introduction of these policy measures, assuming no other incentive to decrease sulphur content of fuel, SO_2 emission would most likely evolve in the same way as fuel consumption, which will increase to 175% as compared to 2005. These measures will therefore have a big impact on SO_2 maritime emission.

EFFECTS OF POSSIBLE NEW MEASURES

In the previous paragraph we focused on policy measures which have already been decided. In this chapter we elaborate on the potential of some possible new measures, focusing only on the effect on emissions, without making statements about cost-effectiveness. The time-horizon of the scenarios is 2020. We will assess the effects of three possible measures:

- Introduction of Selective Catalytic Reactors (SCR) scrubber for main engines from 2010 for new built vessels, combined with a retrofit program for the existing fleet.
- Reduction of maximum sulphur content from 1.5% to 0.5%
- Shore side electricity

To investigate the effect of the use of SCR scrubbers, we had to make some assumptions on possible reduction levels and penetration level of the technology for the retrofit program. We assumed that installation of the scrubber results in a reduction of 90% of NO_x emission[7]. Given that the measure will come into force 01/01/2010 for all new built vessels, we assumed penetration levels of the technology for the existing fleet of 25% in 2015 and 50% in 2020. Effects due to the use of the scrubber on other pollutants other then NO_x were not investigated.
The model run revealed that this measure would result in a 35% reduction of NO_x emissions in 2020 compared to a zero-measure scenario. The relatively low reduction in comparison to the high reduction potential of the scrubber is caused by the scenario assumption that the scrubber is only applied to the main engine emissions. As mentioned before, in the case of Flanders, almost half of all emissions are produced by auxiliary engines.

A further reduction of the maximum sulphur content of marine fuels from 1.5% to 0.5% is expected to have a big impact on SO_2 emissions, as emissions are directly linked to the sulphur content of the fuel. Also, as seen in other runs, a secondary impact on PM10 emissions can be expected. With the model runs, we found that this measure would decrease SO_2 emissions with 45% in 2020 compared to a zero-measure alternative. The secondary effect of low-sulphur fuel on PM10 emissions is estimated to a 15% reduction compared to a zero-measure alternative.
With this measure, SO_2 emissions would fall to a mere 28% in 2020 as compared to 2005, this with increasing traffic at a high pace, a remarkable fact.

The third and final option we investigated is the application of shore-side electricity. As mentioned before, the model has a detailed methodology for calculating in port emissions. Emissions are calculated for each activity, port, vessel type and size. Therefore we were able to simulate the use of shore-side electricity in detail and asses the effect for e.g. only roro-vessels and/or only large (or small) vessels, if desired, in specific ports. We tried one option, being the use of shore-side electricity for all roro and passenger vessels, in all ports. We selected specifically these vessel types, since they use large amounts of energy for accommodation and ventilation purposes.
This measure would decrease total maritime emissions in Flanders with 15% for NO_x, 2.5% for SO_2, 6.5% for PM10 and 19% for CO_2 in 2020, compared to a zero-measure alternative. This measure shows promising results for NO_x and also CO_2, the effect on SO_2 (and PM10) is significantly less explicit, because of the low sulphur fuel which has to be used, causing already low SO_2 (and PM10) emission levels at berth. A specific benefit of this measure is that emissions are simply avoided or more precise, diverted to electricity production, and have effect on all pollutants. Also, this measure reduces in port emissions, which can be perceived as the biggest problem, because often with ports, a major city is nearby and in port maritime emissions which effect local air quality (PM, NO_x) can affect the health of many people.
The use of shore-side electricity is in some ports readily available, yet in most cases on a more or less voluntary basis. Questions may arise concerning compatibility of different technological systems and economic aspects, but this is not the focus of this paper. Our model runs prove that shore-side electricity can be a good option to reduce (in port) maritime emissions.

As a summary we plot the effect of the 3 measures, the introduction of shore-side electricity is combined with the other measures (SCR for NO_x and sulphur content 0.5% for SO_2):

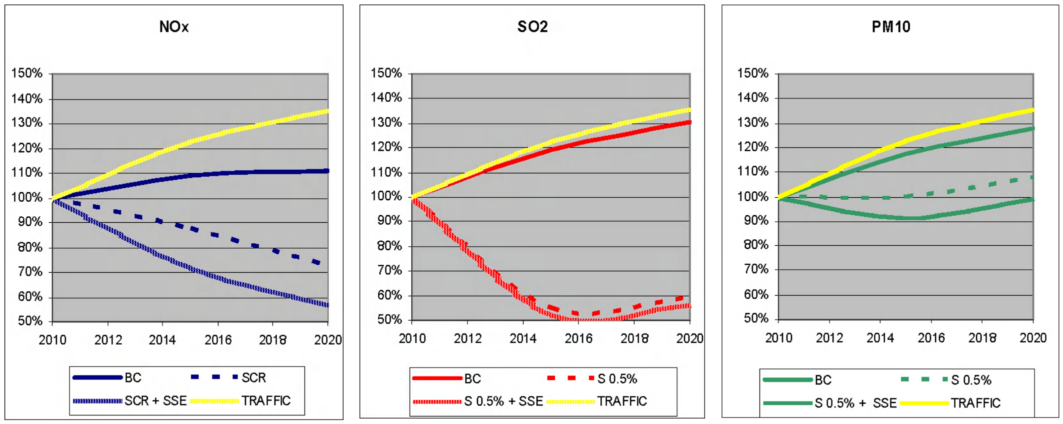

Figure 5: evolution of emissions with several possible policy measures from 2010 to 2020 as compared to emissions in 2010. Left: NO_x; middle: SO_2; right: PM10

CONCLUSIONS

With the model we constructed, we calculated the current and future maritime emissions in Flanders, taking into account the existing legislation. We observed relatively high emission levels, especially with respect to SO_2 emissions and high shares of in port emissions. The policy measures which have been agreed upon, be it in the past or future, prove to have variable success. For NO_x little to no effect was observed by the MARPOL annex VI. For SO_2 big improvements were made by reducing the sulphur content of the fuel.
Furthermore we assessed the effects of possible new measures. An SCR scrubber is very effective to remove NO_x from main engines, yet reduction of total emissions is limited due to the high share of emissions produced by uncontrolled auxiliary engines. This problem is solved when shore-side electricity is used. With this measure emissions of all pollutants produced at berth are avoided. Finally, setting standards for fuel specification, namely with respect to the sulphur content, can lead to high SO_2 emission reduction and can indirectly also reduce PM10 emissions.

Since the share of emissions produced by auxiliary engines is fairly high, especially in this case, and emissions in port, which can be considered the most harmful, are mainly produced by auxiliary engines, it could be advisable that new legislation focuses on measures to reduce emissions of these auxiliary engines. These engines are, compared to the main engines, relatively small and are comparable to engines used in the inland waterway fleet so emissions reduction techniques should be available. Shore-side electricity can be an effective way to eliminate much of the in port emissions, yet, when considering implementation, economic aspects like competition between ports, should be held under close considerations, off course.

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