Development of SOx emissions with regard to MARPOL Annex VI

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Abstract

This thesis presents the development of sulphur oxide (SOx) emissions over the years with special regard to the stringent regulations that came into force in 2015 concerning sulphur emissions from ships in the Baltic and North Sea. I want to research if they had any major effect on a European scale. In the last part, possible future predictions are addressed as well as the impact on human health and the environment.

For the thesis I used a qualitative research method by gathering information from literature, such as books and reports, as well as using official statistics from public authorities, in particular the European Environment Agency.

As a result it was found that the SOx emissions are on a decreasing trend. Although the stricter regulations don't show a big effect on European scale in 2015, improvements in the air quality are definitely traceable on local measuring sites across the Baltic and North Sea. Effects on human health will without exception be positive whereas the impact on the environment surprisingly shows some negative consequences as well.

Language: English Key words: SOx, shipping, environment, air pollution

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1 Introduction

Environmental awareness never seemed higher than it does today. The preservation and protection of the environment is put into focus more and more in all sectors, shipping being no exception to that. And the industry responds – or is forced to do so. In 2015, stricter regulations concerning air pollution came into force in particular sensitive areas, like the Baltic and North Sea. More precisely, sulphur emissions from ships' exhaust fumes were addressed. Although it seems that a big step towards a cleaner future in the shipping industry has been taken with this regulation, the changes might not have been massive and the results are not necessarily solely positive, as one could presume beforehand.

1.1 Objective and Research Questions

My main objective with this study is to show up the development of sulphur emissions over the years with main focus on the implementation of the stricter sulphur regulations in the shipping industry for sensitive areas like the Baltic and North Sea in 2015. Are the stricter limits for ships' emissions noticeable and take an effect on the European scale?

I will also take a look at the present situation. Where are we now, almost five years after the implementation of the regulation? How big was the cut down on emissions really?

In the last part I will address the predictions for the future development of the sulphur emissions and its effects on human health and the environment.

To achieve that I am using a qualitative research method based on literature and data. I gathered information from books, reports and articles and my main source were official statistics, mostly from the European Environment Agency.

1.2 Delimitation

MARPOL Annex VI Prevention of Air Pollution from Ships, which is the background for the stricter sulphur limits, addresses besides sulphur oxides also nitrogen oxides, ozone-depleting substances, volatile organic compounds and others. For the purpose of this study I will only refer to Regulation 14, which handles sulphur emissions (*SOx*).

Furthermore, when investigating the effects of reduction in SOx emissions, the main focus with this thesis lies on the environmental aspect and the impact on human health. The reductions in emissions and the resulting changes and modifications of the ships due to scrubber installations or the use of more expensive fuel for example will of course also have an economical effect which is just as important but shall not be the subject here.

2 Background

International maritime trade has been continuously growing over the last decades and according to experts it most likely continues to do so. Until 2024 a yearly increase of 2.6 to 3.4 per cent is expected. (United Nations Conference on Trade and Development, 2019) Nowadays around 90 per cent of all global trade are seaborne. In Europe, the Baltic and North Sea offer important trade routes and therefore belong to the busiest and most frequented sea areas on the globe. AIS data shows there are more than 2000 vessels on the Baltic every day. (HELCOM, 2010)

As positive as this can be seen for the neighbouring states' economy, it holds challenges as well. The more vessels, the more impact they have on the environment and inevitably on human health and well-being. When one thinks of environmental pollution by ships, most likely oil spillages come into the mind first. The big catastrophes with huge media coverage. Also, garbage - especially plastic waste - in the oceans is a widely discussed topic and very public in the media nowadays. But another important issue that has been brought more and more into focus and risen awareness over the last years is air pollution from ships since it affects not only the environment but also human life. According to the European Environment Agency (2013), emissions from international shipping have contributed to around 60,000 deaths per year worldwide, with impacts being biggest along major shipping routes and coastal areas.

3 Air pollution

There are more than 116,000 merchant vessels operating on this planet right now, if we take small ships like tugs and fishing vessels with a gross tonnage of less than 500 into consideration. But even if we only account for vessels of a GT over 500, there are still more than 63,000 ships crossing the seas. (Equasis, 2019)

In order to be able to fulfil their duties and move through the water, the vast majority of those vessels uses a technique to convert chemical energy into mechanical energy and transfer it onwards into ship's thrust. In other words, fossil fuel is burned to run an engine which can then generate propulsion to the ship. As a result of the combustion process, exhaust fumes are produced and led into the air which we refer to when we speak of air pollution. The exact composition of the gases and particles are of course depending on the exact fuel used, the engine and the combustion process, but in general the following substances are emitted into the air: carbon dioxide (*CO2*), carbon monoxide (*CO*), nitrogen oxides (*NOx*), sulphur oxides (*SOx*), hydrocarbons (*HCs*) and particulate matter (*PM*).

When we consider that each and one of those 116,000 vessels emits these gases and aerosols into the air, it becomes clear that they contribute to air pollution on a global scale. Not only do they have an impact on the climate, for example with greenhouse gas emissions like CO2 that contribute to the warming of the earth, they also leave a footprint on the environment in form of acidification of the water or eutrophication of soil and water.

Studies found out that almost 70 per cent of the exhaust emissions from vessels appear within 400km of land. Cities located at the coastal areas are therefore much more affected by the emissions coming from ships, although they can also spread much further inland given the right – or better said wrong – climatic circumstances. For port cities, emissions from shipping are even the biggest source of urban air pollution.

In addition to the impact on the climate and environment, emissions of exhaust gases and particles also have a negative effect on human health, they might even be toxic. They cause problems like respiratory diseases or premature deaths from cardiopulmonary diseases, in other words diseases that affect the heart and lungs. According to the World Health Organisation, in 2012 one in eight of the total deaths worldwide was caused by air pollution exposure, which correlates with a total number of 7 million people. (Andersson, 2016)

Needless to say that there is not only room but the strong need for improvement, not only to protect and safe the environment, but also to save our lives and that of future generations. With the tighter Regulation of *MARPOL Annex VI Prevention of Air Pollution from Ships* concerning sulphur oxides the shipping industry is forced to take a next step towards a cleaner environment.

3.1 Sulphur Oxides

Sulphur itself is a naturally occurring chemical element and as that non-toxic. It can be found in seawater, sedimentary rocks or the soil. It is essential for biochemical functioning and important for all living organisms.

The problem with sulphur as a harmful pollutant arises as soon as it gets burned, reacts with oxygen and forms sulphur oxides, the biggest part being sulphur dioxide (SO_2). That happens for example when burning coal or fossil fuels, in which sulphur is naturally stored. By combustion it gets released and enters the atmosphere as SO_2. It can form other oxides as well, so this whole group of sulphur oxides is summarised as SOx.

When sulphur oxides come into contact with water, sulfuric acid is formed which can harm the environment because of its acidic properties. A quite well-known term in that context is acid rain which came into the focus of the public already in the 1970s. This acidification leads to changes and damages of terrestrial and marine environment. Soil and vegetation, especially forests, water and aquatic life and even buildings and structures are prone to the negative impacts of acidification.

Apart from the harmful impacts on the environment, SOx emissions are also linked to negative effects on human health. It is known that besides the reaction to sulfuric acid a certain percentage of the SOx emissions reacts and forms particulate aerosols in the atmosphere. These particulate matter or PM have noxious effects on the human body and can worsen or even cause health problems like asthma or lung cancer. (Vestreng, V. et al, 2007)

Sulphate aerosols are also found in clouds. The more aerosol particles they contain, the more sunlight is reflected back to space and cannot reach the earth's surface. Due to this effect, SOx emissions contribute a little part to the cooling of the earth.

In shipping, SOx emissions are obviously directly related to the fuel that is used and its sulphur content. The higher it is, the higher the SOx content in the exhausts. Most vessels – in 2007 around 70 per cent – use heavy fuel oil (*HFO*), which is the cheapest but also has the highest sulphur content compared to other distillate fuels like marine diesel oil for example. In total, ships use around 300 million tons of fuel per year. With HFO being the most of it, the fuel that is used for shipping has a sulphur content that is around 2700 times higher than the fuel used in road transport. (Andersson, 2016) (Moshiul, 2019)

In order to reduce the SOx emissions on board, two main options are used today. Either the ships change from HFO to another distillate fuel with less sulphur content which is more expensive or they install a technology for exhaust gas cleaning, a so-called scrubber. When using a scrubber, HFO can still be used. The system then cleans the exhaust gases in the funnel, before they enter the atmosphere, by water-washing and removes the sulphur oxides. (ShipInsight, 2019)

4 MARPOL Annex VI

The International Convention for the Prevention of Pollution from Ships (*MARPOL*) functions as "the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes" (IMO). It was elaborated by the International Maritime Organization, a specialized agency of the United Nations dealing with matters concerning international shipping, during the 70s after several accidents with tankers happened that had a huge environmental impact and when environmental awareness was coming more and more into public focus. (Andersson, 2016) Over the years, some Protocols have been adopted, new Annexes were added, and the Convention has been updated by amendments. The Annexes cover the regulations for pollution by oil, noxious liquid substances in bulk, harmful substances carried in packaged form, sewage and garbage. Annex VI, which handles air pollution and greenhouse gas emissions from ships' exhaust fumes, is the latest addition to the Convention and entered into force in May 2005. It regulates emissions into the air such as ozone-depleting substances, nitrogen oxides (*NOx*), volatile organic compounds (*VOC)* and – under Regulation 14 – the above-mentioned sulphur oxides (*SOx*). Furthermore, it allows to set up so called emission control areas where the standards for SOx and/or NOx levels are even more strict. (IMO, 2008)

4.1 Emission Control Areas

As mentioned in the beginning, the Baltic is a highly frequented area, especially on the main traffic routes, which Figure 1 clarifies well. Although it is quite small compared to other seas, around 15 per cent of all goods worldwide are shipped on those routes on the Baltic Sea, not to mention the ferry and seasonal cruise ship traffic. Geographically, the Baltic Sea is unique because of its straits of Öresund and the Belt Sea. They are the only natural connection between the North Sea and the Baltic which leads to very little water exchange simply because they are very shallow and narrow. As a result, excess nutrients like nitrogen – that can enter the water for example via sewage disposal from ships - cannot disperse and remain in high concentrations in the water. That can lead to several problems for the marine environment and its ecosystems and might end up in the abandoning of indigenous species. (Andersson, 2016)

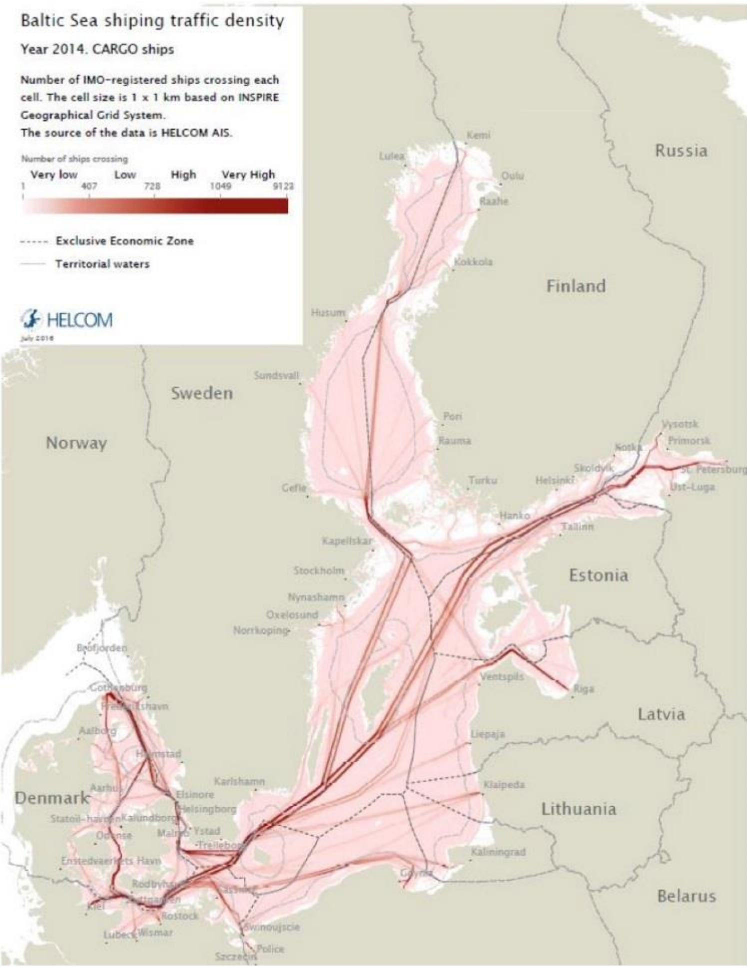

Figure 1 Cargo Ship Density in the Baltic in 2014

Having said that, it is quite understandable that in 2005 the IMO declared the Baltic Sea as particularly sensitive and therefore as the first Emission Control Area (*ECA*), sometimes also referred to as SECA which stand for sulphur emission control area. One year later, the North Sea was established as an ECA as well, followed by regions along the North American east and west coast, Hawaii and the U.S. Caribbean (Figure 2).

Figure 2 Global ECAs

4.2 Sulphur content limits

When MARPOL Annex VI came into force in 2005, under Regulation 14 a gradual restriction in the SOx emission limits was planned over a period of 15 years. Initially, the sulphur content of fuel was restricted to 4.5 per cent per mass globally and 1.5 per cent in the more vulnerable ECAs. In 2012, the global limit was then set to 3.5 per cent. In the beginning of next year, January 2020, the last step, a global reduction to 0.5 per cent sulphur content, is about to come into force. For ECAs the first change in restriction took place in 2010 when the sulphur limit was reduced to 1.0 per cent and finally, in January 2015 the goal of 0.1 per cent was reached. Table 1 visualizes the stepwise reduction. (IMO)

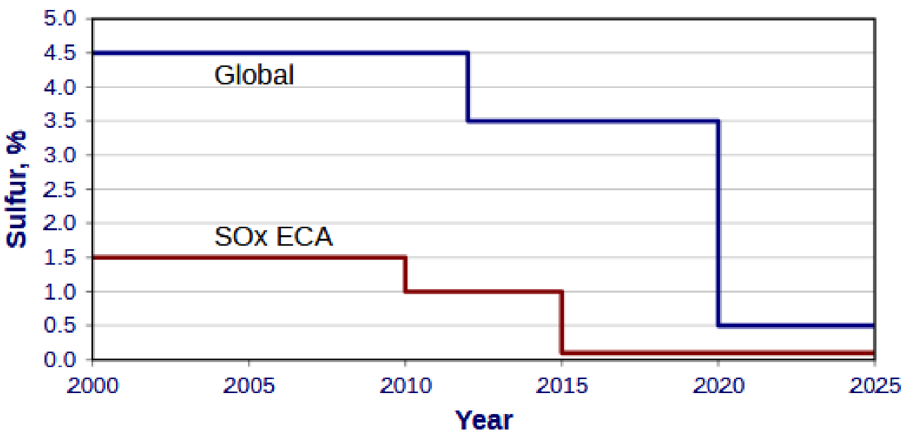

Table 1 MARPOL ANNEX VI Regulation 14 Fuel Sulphur Limits

5 Development of SOx emissions

As pointed out in the beginning, the aim of this thesis is to find out how the sulphur emissions developed and what impact the strict reduction of the sulphur emissions in the emission control areas in 2015 had, particularly for Europe and North Sea and Baltic regions. I will also try to find out how the situation looks now, almost 5 years later, and what the prognosis for the future are. To analyse that, the following chapter starts with a retrospect to take a look at the trend regarding sulphur emissions until 2015. Following that, the situation around 2015 will be focused on before getting to the present state and future models.

5.1 SOx emissions before 2015

Global anthropogenic sulphur emissions have been steadily increasing for decades due to industrialization and the increase in usage of fossil fuels as the primary energy source. (Vestreng, V. et al, 2007)

As table 2 illustrates, they have reached their peak in almost all parts of the world in the 1970s to 1980s with a maximum value being higher than 40 million metric tonnes in western Europe. Since then, a significant decrease (except for Asia – especially China - and Middle East) can be observed.

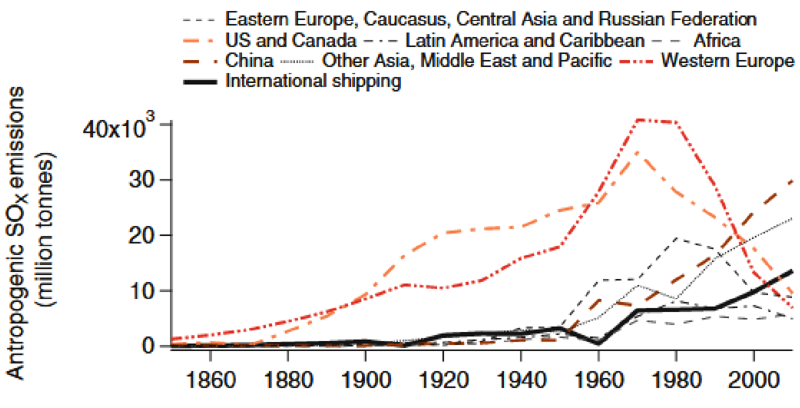

Table 2 Global antropogenic SOx emissions

Tables 3 and 4 emphasise this progress with the focus on Europe solely. According to table 3, the increase of emissions has only been interrupted by a few years of decrease during and shortly after World War II. After this recess, the SOx emissions had a sharp increase and even peaked around 55 million metric tonnes before – similar to table 2 – rapidly decreasing to around 15 million metric tonnes in 2004. The difference in the peaks can be explained since in table 2, Europe is represented by two different curves for western and eastern Europe. When adding those together, we approximately get the value presented in table 3. Table 4 clarifies, apart from the total emission trend which gives the same results as the other two statistics, the relative emission reduction in Europe per year since the 1980s. In the 25 years from 1980 to 2004 the European sulphur oxide emissions have in total declined by ca. 73%. (Andersson, 2016)

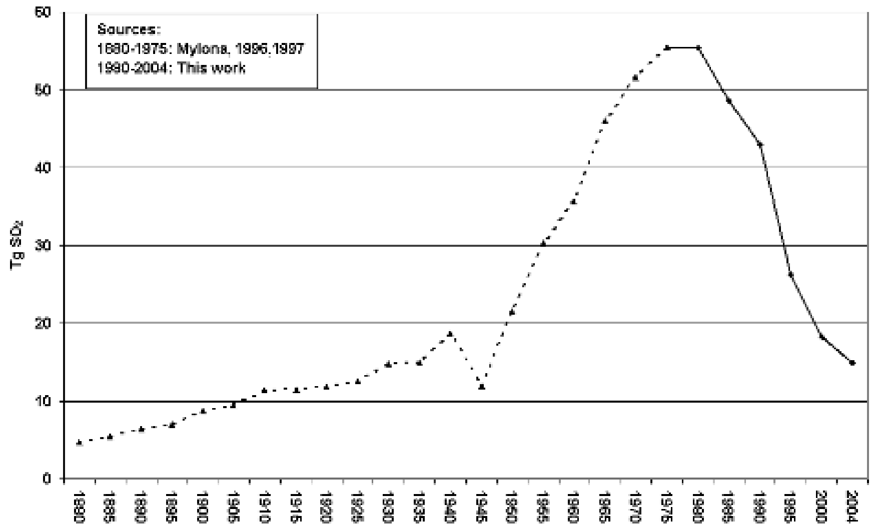

Table 3 Historical development of SOx emissions in Europe

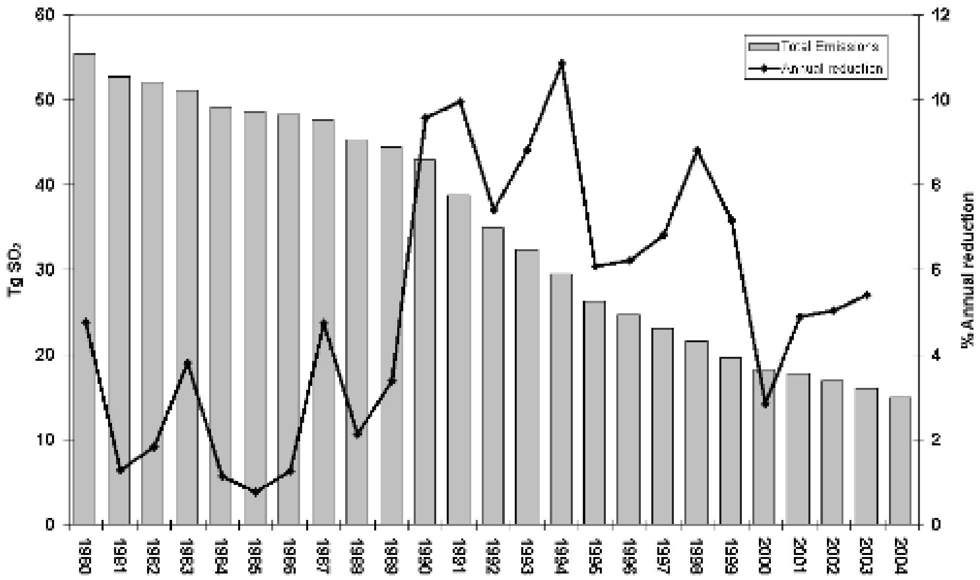

Table 4 Total SO_2 emission trend and relative annual European emission reduction 1980–2004

The reasons for the rapid improvement of air quality are, according to Vestreng et al. (2007), for example new and stricter regulations for land-based sources concerning SOx emissions during that time, the economic situation or new technologies and fuels.

When focusing on the role that shipping played during this time, it is interesting that although global emissions decreased in total, the SOx emissions from ships still rose and contributed a huge part. Table 2 shows that since the 1960s the emissions from shipping have increased more rapidly than before and, unlike the global trend, they continued to do so until recent years. Since the 1990s a sharp increase was recorded and according to these studies, international shipping was responsible for 4 to 9 per cent of the global SOx emissions in 2000. In 2010 the shipping industry emitted more sulphur oxide than whole Europe or North America.

Experts see the steadily increasing shipping activity as one reason for that. On the other hand, it is stated that the values for shipping are an estimation and can include huge uncertainties, so we can’t be absolutely sure the exact values are correct, but they give a good overview of the trend anyway. (Andersson, 2016)

At this point it has to be remarked that the emissions of the international shipping industry (and aviation for that matter) are not included in the statistics of table 3 and 4. Reason for that is that the statistics are based on a certain programme for monitoring and evaluation of long-range pollutants in Europe, which again consists of data concerning national sources of air pollution that each European state submits. International aviation and shipping fall under different categories and are therefore not necessarily always included in the final reports.

Studies from the European Union emission inventory report (European Environment Agency, 2019) show the declining trend for SOx emissions continuing also until 2015. Table 5 shows up that between 1990 and 2015 the emissions decreased by more than 80 per cent. In absolute numbers, that means a reduction from about 28000 Gg (corresponds to 28 million metric tons) in 1990 to around 6000 Gg in the more recent years before 2015, as seen in table 6. The shipping sector alone which is the major contributor under the category *Memo Items* had a reduction from about 900Gg to 600Gg in 2013, making it a reduction of one third of its emissions. What is interesting there though is that from 1990 until 2000 the emissions were still, like the global trend observed in table 2, rising to a total of around

1100Gg. It is only since then that a strict reduction can be observed. The reductions in the land-based sectors however were the biggest contributor so even the still rising trend in the shipping industry from 1990 to 2000 is of no consequence when looking at the European downward trend in total.

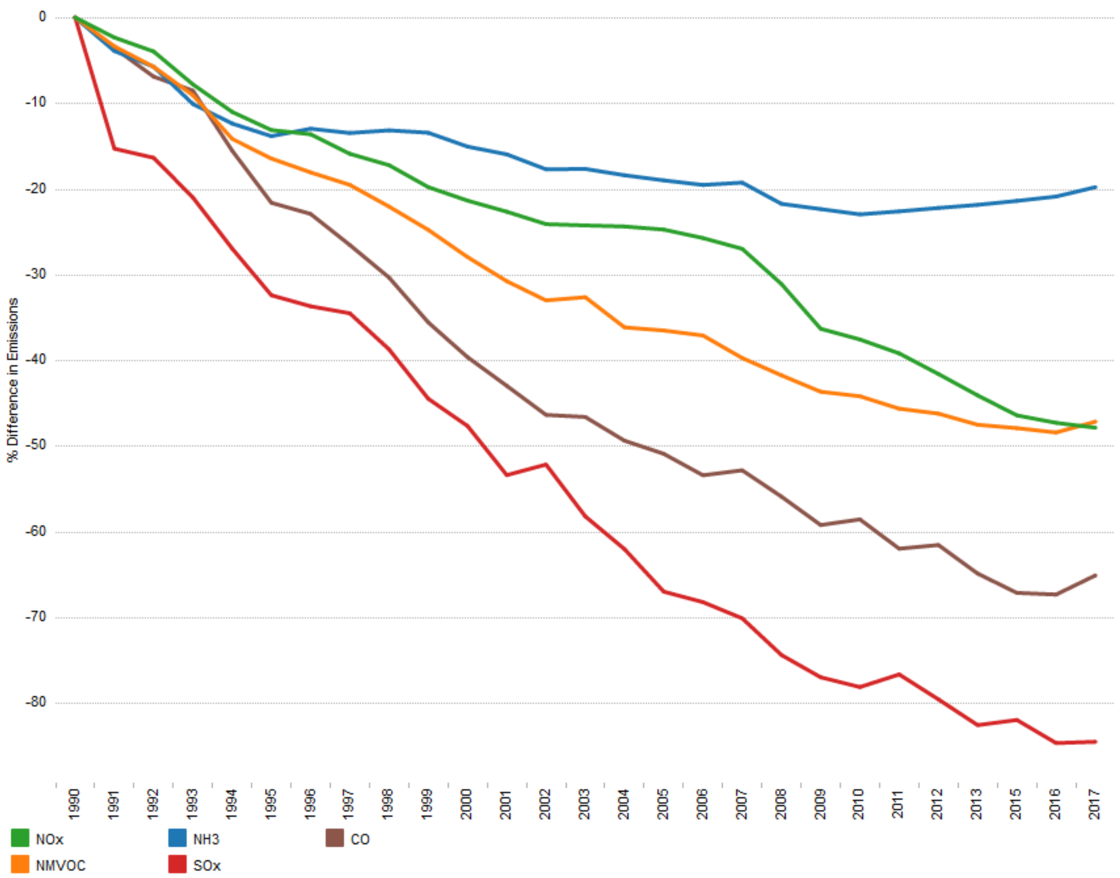

Table 5 EU emission trends for main air pollutants 1990 – 2017, including intl. aviation & shipping

Table 6 also shows, in 2013 more than half of the European total SOx emissions originate in the energy production and distribution sector which therefore is the biggest land-based polluter. International shipping contributed 16 per cent of the total sulphur emissions in 2014, making it the second largest contributor after the non-transport sector, table 7.

			Year				
Country	Pollutant	EEA sector aggregations	1990	2000	2013	2015	2017
EEA-33	SOx	National total for the entire territory (..	26'710.471	12'407.066	5'260.835	4'822.969	4'742.768
		Energy production and distribution	17'112.800	8'125.261	3'066.865	2'792.660	2'671.726
		Energy use in industry	4'298.413	1'932.726	975.780	942.222	952.325
		Commercial, institutional and house..	3'125.438	1'004.330	741.713	660.397	670.680
		Industrial processes and product use	702.838	390.129	255.947	243.138	260.358
		Non-road transport	324.464	249.840	81.552	63.111	72.733
		Road transport	605.332	122.520	5.411	5.517	5.812
		Waste	17.149	5.400	2.964	2.792	2.647
		Agriculture	5.993	1.861	0.640	0.666	0.632
		Other	0.011	0.011	0.012	0.011	0.011
		Memo Items	893.274	1'099.149	613.732	511.621	563.790

Table 6 European SOx emissions for specific years in Gg, international shipping included in Memo Items

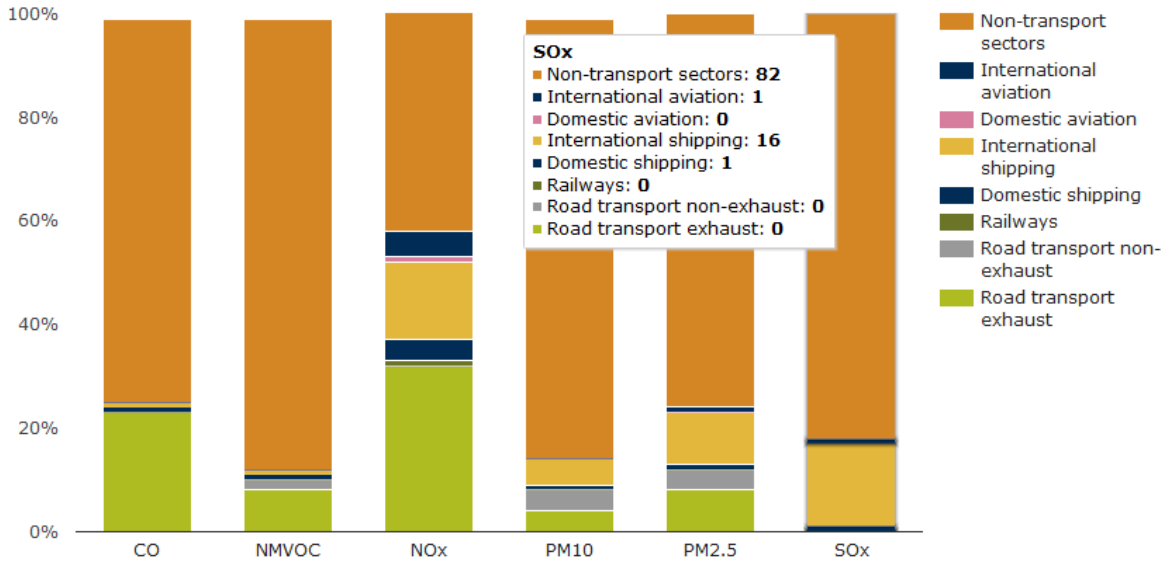

Table 7 Contribution of the transport sector to total emissions of the main air pollutants, 2014

Summing up, we can point out that already from 1980, SOx emissions from land-based sources have been steadily decreasing on a global scale. Emissions from shipping however were still increasing, in Europe until 2000, before declining here as well. While the land-based sources from the non-transport sectors are still the major contributors in Europe, international shipping emits around 16 per cent of the sulphur oxides. In 2013 that matches a total value of 614Gg.

In that context, Annex I shows nicely the SOx emissions over Europe in 1990 compared to 2012, where we see that the reduction in emissions mostly comes from land-based sources.

5.2 SOx emissions around 2015

When now comparing the SOx emissions from 2013 to 2015, during which the MARPOL regulation 14 for Baltic and North Sea as an ECA came into force and set the limit from 1 per cent per mass to 0.1 per cent, we can find a reduction in SOx emissions from around 5900 Gg to 5300 Gg (Table 6) when adding the memo items to the national total. That matches with a relative reduction of around 10 per cent from 2013 to 2015. It makes the appearance that the stricter regulation of emissions in Baltic and North Sea therefore had an impact. With remark to table 5 it has to be said though that also in the previous years, as pointed out before, a reduction of emissions was noted, mostly due to drop downs in the land-based non-transport sectors which are the biggest contributors still. When evaluating the curve we see the trend continuing and not showing any striking difference compared to the years before.

Taking a look at the emissions from shipping industry only, the reduction was 17 per cent, from 614 Gg to 512 Gg.

A closer look at the statistics for the transport sector reveals some interesting information as well. According to table 8, in 2014 the SOx emissions were 38 per cent of the 1990s emissions which function as the point of origin for the 100 per cent. The same emissions were also evaluated excluding international shipping which were 12 per cent. So the emission from the shipping industry were 26 per cent compared to 1990. For 2015, total SOx emissions were 33 per cent, excluding shipping even only around 11. When subtracting those we get a value of 22 per cent for international shipping. Now it shows quite clear that the reduction of the total SOx emissions from 2014 to 2015 was 5 per cent, whereas the difference in emissions excluding shipping only accounts for minus 1 per cent. International shipping therefore is responsible for the drop down of the 4 per cent in 2015 compared to 2014, in other words 80 per cent of the reductions of emissions in the transport sector from 2014 to 2015 are due to shipping industry.

With a remark to table 7 and chapter 6.1, it has to be noted though that the transport sector in total only sums up for a small fraction, more precisely 16 per cent, of the total SOx emissions in Europe compared to the more than 50 per cent that the energy production and distribution sector accounts for. What looks like a lot, is therefore relatively seen in the statistics on the European scale or even the global not that big of a reduction.

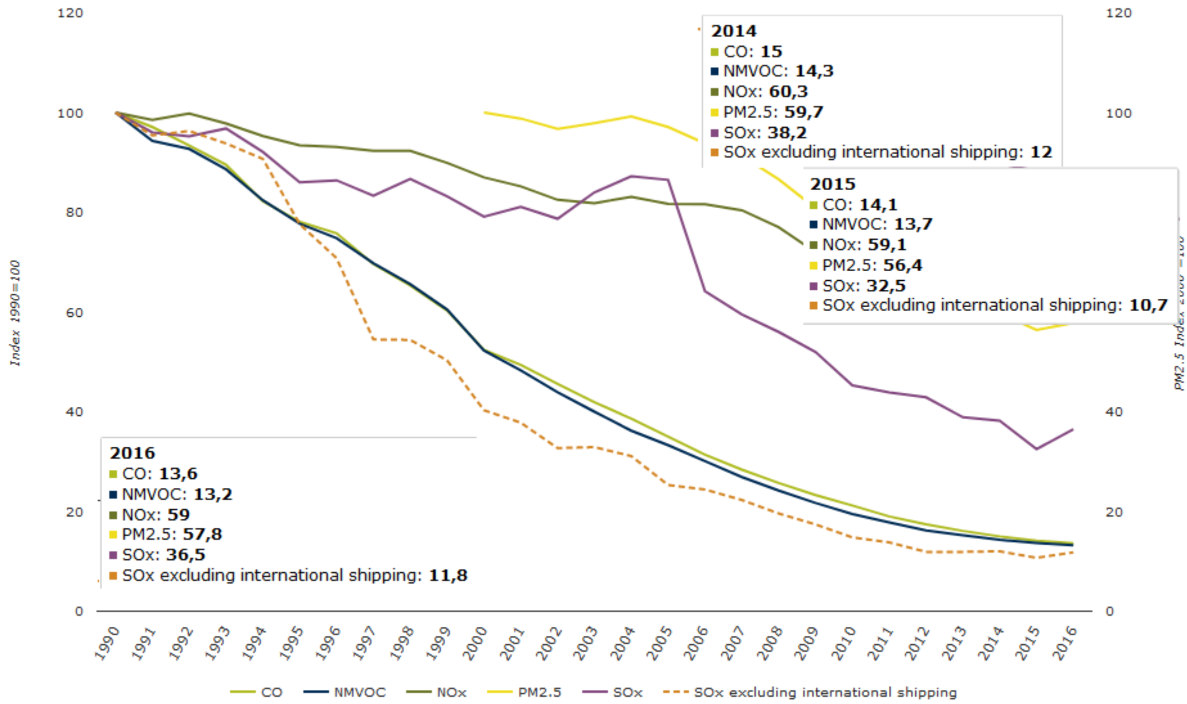

Table 8 Trend in emissions of air pollutants in transport sector in Europe

On a more regional scale though, the implementation of MARPOL Annex VI Regulation 14 indeed took an effect, both in the Baltic and North Sea areas. In Denmark, the air quality was monitored with new techniques on the Great Belt bridge as well as via airplanes. The measurements close to a major shipping route in 2015 showed a reduction of SOx concentration in the air of 60 per cent compared to the year before. Even on inland measuring stations, the reduction was as high as 50 percent. (Miljø- og Fødevareministeriet, 2015)

For the Rotterdam port area, the evaluated data showed a SOx concentration that was 24 to 37 per cent lower than in the previous year, whereas the shipping intensity stayed the same, so it cannot be explained with less ships contributing to air emissions, but very likely with the stricter SOx limits.

Two monitoring sites in south Sweden indicated a 50 per cent reduction in SOx levels in the air and on the Plymouth coast, a three times lower concentration was measured. (CE Delft, 2016)

In the German bight, measurements have been conducted on a small island called Neuwerk which is located in vicinity to a major shipping lane into Elbe river towards Hamburg port or Kiel canal, with more than 100,000 ships passing per year. The results confirm the findings from the above-mentioned statistics. Here, the absolute SOx levels were reduced by around 66 per cent and the contribution from shipping as a SOx emission source besides land-based sources dropped from 41 per cent to 14 per cent. Table 9 shows considerable differences in the sulphur oxide concentration in the air before and right after the implementation of the more stringent rules. (Seyler, A. et al.)

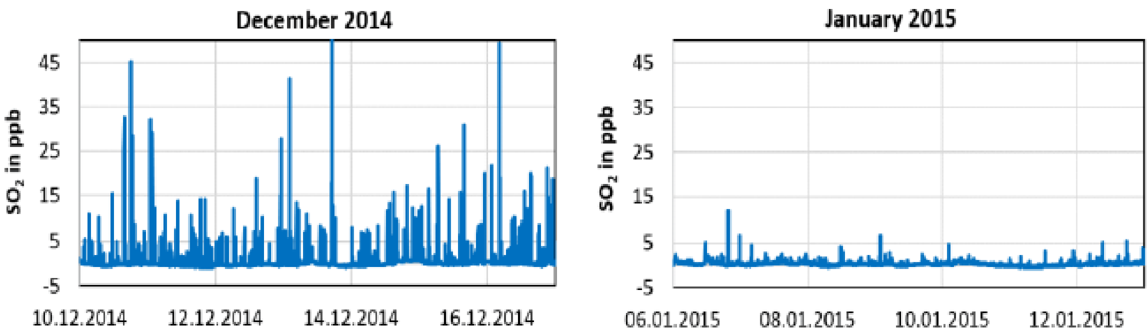

Table 9 SOx concentration in air on Neuwerk, Germany

For the Baltic Sea area as a total, SOx emissions from ships have measurably reduced by 88 per cent. In 2014 all vessels on the Baltic emitted 81 kilotons of sulphur oxides. (Johansson & Jalkanen, HELCOM Baltic Sea Environment Fact Sheets, 2015) Compared to 2015, after the compulsory restriction, only 10kt were recorded. What is remarkable is that also the quantities of harmful particulate matter in this sector has decreased, see table 10. Whereas in 2014, 16kt of PM was emitted, it was only 10kt in 2015, which is a decrease of 36 per cent. The results show that SOx emissions indeed are to a certain percentage related to the forming of particulate matter, as was mentioned in chapter 3.1 (Johansson & Jalkanen, 2016)

A visualization of the results is shown in Annex II, where a geographical distribution of SOx emissions over the Baltic Sea are generated using the Ship Traffic Emission Assessment Model STEAM.

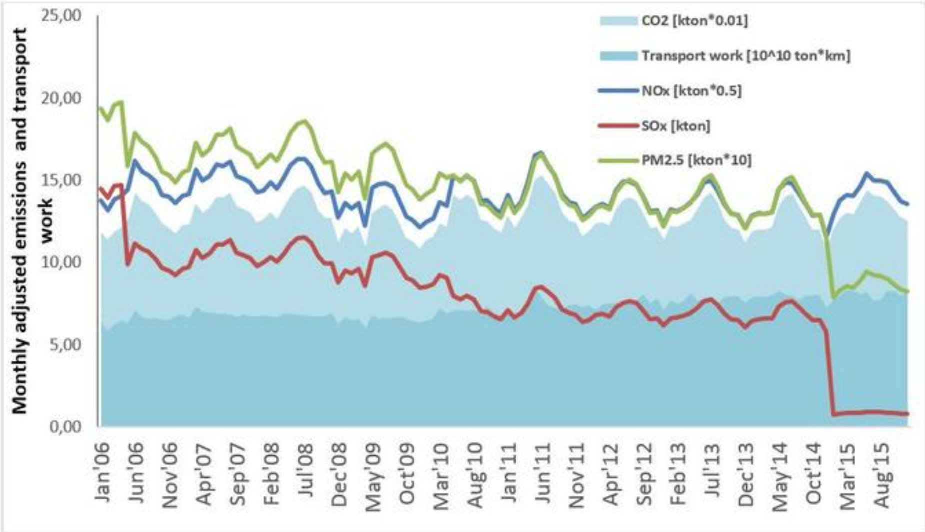

Table 10 Emissions for Baltic Sea area from 2006 to 2015

Summing up, we can note that the downward trend of SOx emissions in Europe also continued for the years 2014 and 2015. Although the MARPOL regulations concerning the Baltic and North Sea came into force, a very striking or noticeable difference compared to the years before did not happen, at least on European scale. The specific transport sector shows a bigger reduction in SOx emissions for shipping than in the years before, but the total effects of it are minor compared to the other contributing land-based industries. For coastal regions though, significant differences in sulphur emissions from ships could be measured in both North Sea and Baltic. Various measuring sites report a reduction of sulphur content in the air up to 60 per cent showing that the sulphur restriction indeed was complied with and noticeably improved air quality. For the whole Baltic region, the emissions from shipping decreased by 88 per cent to a total of 10kt compared to 81kt in the previous year. In addition, also a reduction in particulate matter was noticed after the beginning of 2015.

5.3 Development until now

The statistics for the years from 2015 until now don't hold large surprises. As expected, the declining trend for SOx emissions (and PM) from vessels in the Baltic continues also until 2018, as seen in table 11. The total amount from IMO registered ships adds up to 9kt for SOx as well as for PM. When taking into consideration the smaller ships that don't fall under IMO registration, an additional 1kt accrues respectively. So compared to 2015 the situation more or less stayed the same emission wise. (Jalkanen & Johansson , 2019)

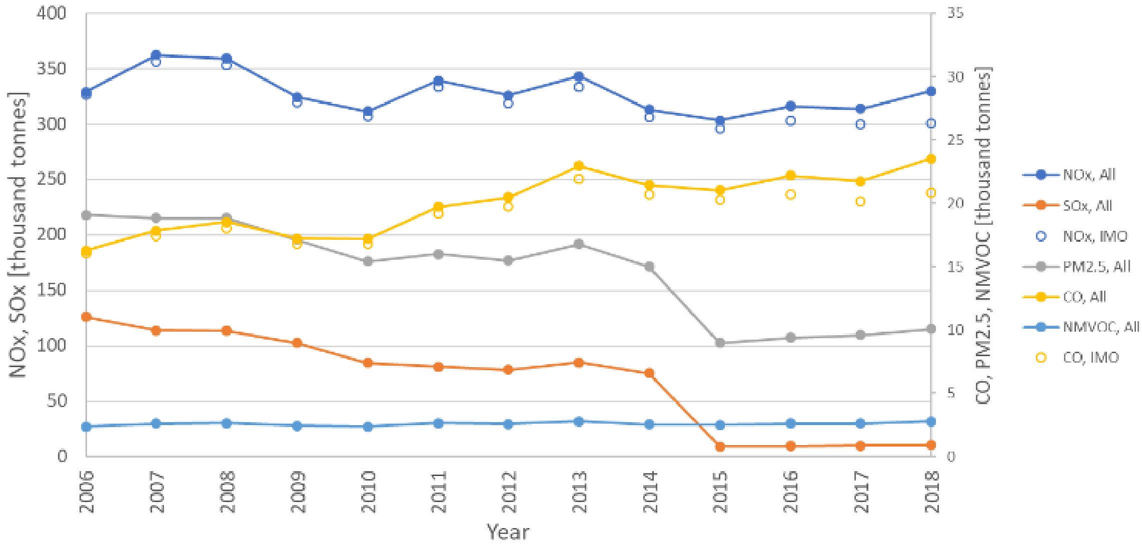

Table 11 Emissions of main air pollutants from Baltic Sea fleet

On the European scale, table 6 shows that the total SOx emissions have decreased by 28 Gg from 5335 Gg in 2015 to 5307 Gg in 2017, whereas the emissions from shipping even increased, what is a bit of a surprise. In 2015 vessels contributed 512 Gg, in 2017 it was 564 Gg. An explanation for that most probably is the yearly growth in maritime trade which correlates with more shipping traffic.

In total, when we compare the emissions from 2017 to 2000 though, it is clearly visible that the downward trend continues, also in the shipping sector. The total emissions decreased by 62 per cent, where the energy production sector even reduced the pollutants by 67 per cent. Shipping almost halved its emissions with a reduction of 49 per cent.

In the transport sector, as seen in table 12, international shipping now accounts for around 11 per cent, whereas in 2014 it was still 16 per cent. The share of non-transport sectors on the other hand has increased from 82 to 87 per cent and remains the biggest contributor to air pollution from sulphur oxides.

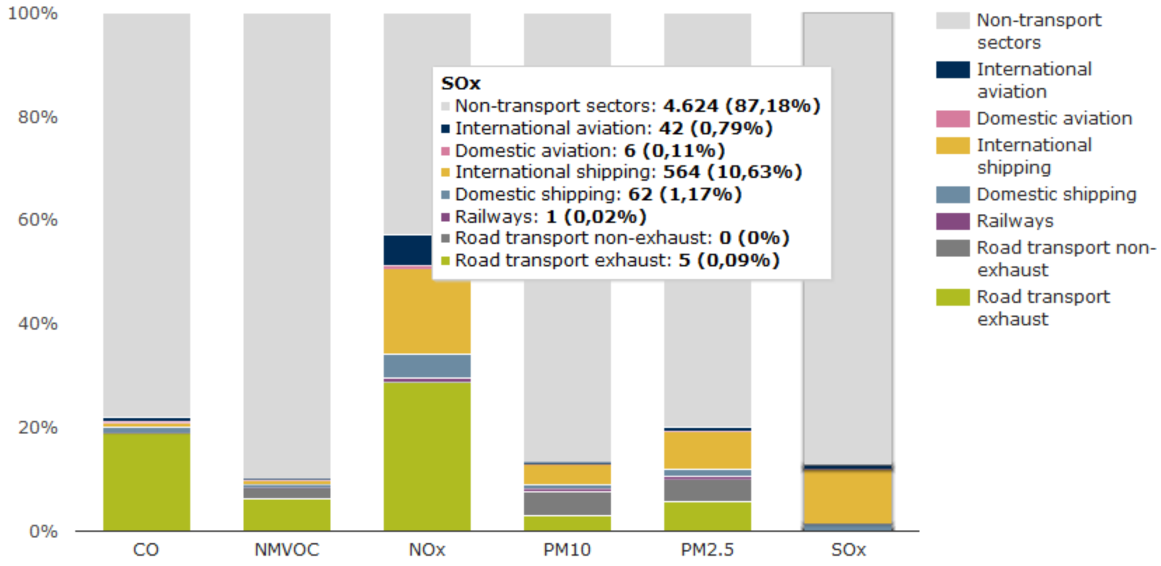

Table 12 Contribution of the transport sector to total emissions of main air pollutants, 2016

5.4 Future prognosis

Based on data from the previous years and model calculations, scientists are able to develop scenarios on how the trend for SOx emissions most likely will continue in the following years to come. Since the Baltic and North Sea are ECAs already, there won't be any major changes because the regulations concerning sulphur emissions from ships concerning these areas won't change in the next years. What could have an impact though is the contribution of LNG as fuel. LNG doesn't contain any sulphur at all and therefore ships using that as their energy source will not produce SOx emissions. So in case more ships are able to and decide to use LNG in the future, it will have a positive impact on the contribution of shipping to the SOx emissions in the Baltic and North Sea. (Matthias, 2016)

As stated before, from the beginning of 2020 the sulphur cap will be in force, meaning that the sulphur content in fuel will be limited to 0.5 per cent for all ships worldwide. This will not have an effect on the SOx emissions in the Baltic or Norths Sea, but for the other sea and coastal areas, air quality might improve significantly.

According to the European Environment Agency (2018), on European scale the emissions from land-based sources will continue to decrease as well. Therefore, the contribution of the shipping industry to SOx emissions will relatively- seen even increase. A model calculation from Amann (2010) expects the emissions from international shipping to be

12kt in the Baltic and 28kt in the North Sea in 2020. The total global emissions in that year will be 2649kt, compared to 663kt in 2030, which matches a decrease of 75 per cent. The effect of the reduction in 2020 can be seen clearly. The Third IMO Greenhouse Gas Study (IMO, 2015) draws quite a similar conclusion. According to it, in 2050 the SOx emissions will be 30 per cent of the 2012 level assuming that ECAs stay constant. If even more ECAs will be established, in the Mediterranean for example, emissions could even decrease to 19 per cent.

6 Health and environmental impacts

Healthwise the reduction of sulphur emissions will pay out positively. According to studies from Winebrake (2009), a 50 per cent reduction in premature mortality can be reached which is due to the decrease of particulate matter formed from sulphur oxides. That means a total of avoided premature deaths between 30,000 and up to 45,000. The areas that benefit the most are coastal regions, especially in Asia and Africa and Latin America which shows again that the direct impact of sulphur emissions mostly occurs on a local scale. Morbidity rates in those areas are positively affected as well. Other studies emphasise the results and furthermore expect an avoidance of 350 cases of infant mortality as well as a reduction of more than 50 per cent concerning morbidity impacts on respiratory symptoms. (Amann, 2010) For childhood asthma morbidity due to shipping for example, a reduction from 14 million children that are affected to 6.4 million can be expected. (Sofiev et al, 2018)

As mentioned above the particulate aerosols formed by SOx also contribute to the sun’s radiation that reaches the earth and therefore affect the climate. Shipping has due to its high usage of sulphur containing fuel a net cooling effect to the climate. With the drastic reduction of SOx emissions in the future, this cooling effect might decrease, and shipping could then affect the warming of the earth not only because of its CO2 emissions but also because of the reduction of SOx emissions. It is uncertain though if the effect is big enough to actually contribute to the climate change and hard to predict since it depends on so many other factors and contributing substances as well but it might be something to investigate further. (Andersson, 2016) (Vestreng, V. et al, 2007)

With the stringent regulations for sulphur emissions, the number of vessels that install scrubbers to comply with the rules are likely to increase. It is still a quite new field of research, but studies have shown that the scrubber impact on the environment might not be neglectable. When the exhaust fumes from the ship come into contact with the wash water, it will be contaminated. Though it gets treated before it is allowed to be discharged into the sea, it can cause a lowering of the pH level, a rise in temperature, clouding and an entry of pollutant residues and sediments. Although the concentrations of the pollutants are small and lie under the allowable limits, they could stay in the water and accumulate with an increased use of scrubbers over time which can affect and harm the marine environment. (Umweltbundesamt, 2014)

7 Conclusion

After analysing different available material it turned out that sulphur emissions have been on a decreasing trend since 1980 already. Land-based industries had the biggest impact in that, whereas emissions from the shipping sector were still increasing even. In Europe a total reduction of SOx emissions of 81 per cent can be seen from 1990 to 2017. A reduction in the emissions from shipping de facto only started from 2000, but since then emissions have decreased by almost 50 per cent.

Around 2015, the tightening of the MARPOL regulation is not necessarily visible in European statistics simply because no bigger reductions occurred compared to the years before. On a more regional scale though an improvement of air quality was clearly verifiably. Various measuring stations in North Sea and Baltic proofed a reduction of sulphur emissions and even particulate matter in the air. An improvement of up to 60 per cent could be seen in 2015 compared to the year before and for the whole Baltic emissions decreased by 88 per cent.

Today the downward trend still continues, in land-based industries as well as in the shipping sector. It has to be remarked though that the steady increase in the shipping industry leads to more traffic and hence more emissions in absolute terms compared to 2015, simply because there are more ships emitting pollutants to the air.

In the next year, a bigger change will presumably be noticeable when the sulphur limit in fuel will be reduced from the present 3.5 to 0.5 per cent worldwide. All ships will then be affected. For the North Sea and Baltic no major changes are expected, but globally a reduction of SOx emissions of 75 per cent could occur.

That will, according to experts, definitely result in the lowering of premature mortality and morbidity rates. Thousands of people, mostly in ports and coastal regions, will be affected and benefit from it.

The impact of the SOx reductions on the environment could result in changes in the radiation balance which means that the net cooling effect that the shipping industry nowadays has, might be reduced and that shipping could actually contribute to the global warming. More research there is needed though to make concrete statements. The same applies to the environmental effect that the use of scrubbers have. There are indications that the wash-water that is discharged to the sea might have negative impacts on the marine environment.

8 Discussion

Referring to the initial question on how the sulphur oxide emissions developed and what big of an effect the implementation of regulation 14 had, the evaluated data demonstrates that not only in Europe, but also on the global scale, the SOx emissions have been declining from as early as the 1980s and are still continuing to do so – according to various model calculations even in the future. The implementation of regulation 14 of MARPOL concerning the Baltic and North Sea does not clearly stand out in the statistics though. When looking at the emissions on a more local scale however, vast improvements of the air quality are visible.

Concerning the impacts that the reduction of SOx emission has regarding human health, experts agree that they are solely positive. Especially premature mortality and morbidity will decrease and therefore bring an improvement to the life of thousands of people.

What turned out to be a bit surprising though is that contrary to the presumption that the SOx reduction will also have only positive impacts on the environment, some studies show that this might not be the case. Emissions from ships could still remain a source of acidity because of the use of scrubbers whose wash-water could affect the marine environment when discharged into the sea. Isn’t that just a shifting of the problem from air to water?

Also, the effect of particulate matter that is formed by sulphur oxides on the radiation of the sun is a topic that has to be investigated further. When the reduction of SOx emissions and as a result of it PM, which act as a cooling agent, has a serious effect on the global warming, shipping industry could contribute more to it than it already does anyway.

With the reduction of sulphur content in fuel from 3.5 to 0.5 per cent next year, a bigger change will most likely occur, especially on the global scale. How the SOx emissions in comparison to the expected trend really develop remains to be seen and will be interesting to follow. A topic to research further in that regard could then be the question if all ships are actually complying with the regulations and what options authorities have at all to determine that, for example in the middle of the oceans.

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Figure 2: https://media.springernature.com/original/springer-static/image/art%3A10.1007%2Fs12544-015-0161-9/MediaObjects/12544_2015_161_Fig1_HTML.gif

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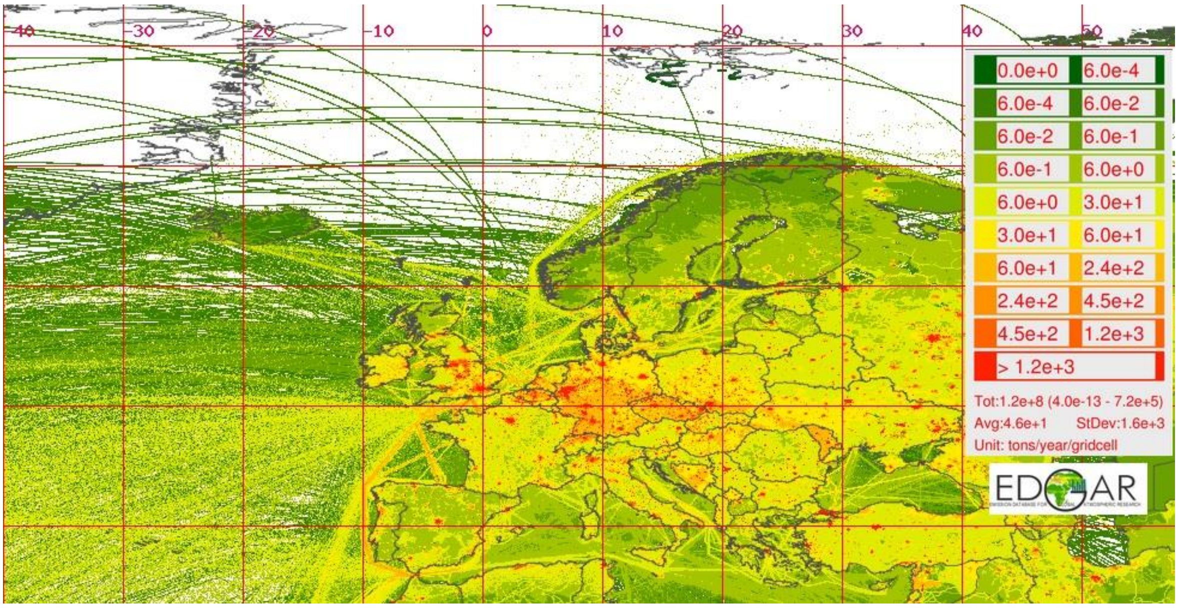
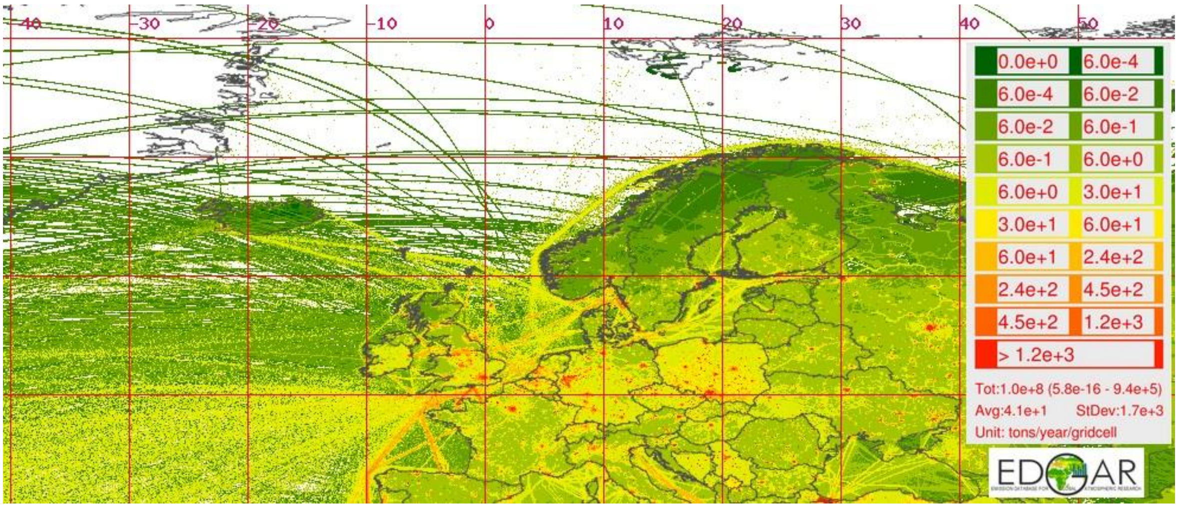
10 Annex I: SOx emissions 1990 and 2012, EDGAR Model





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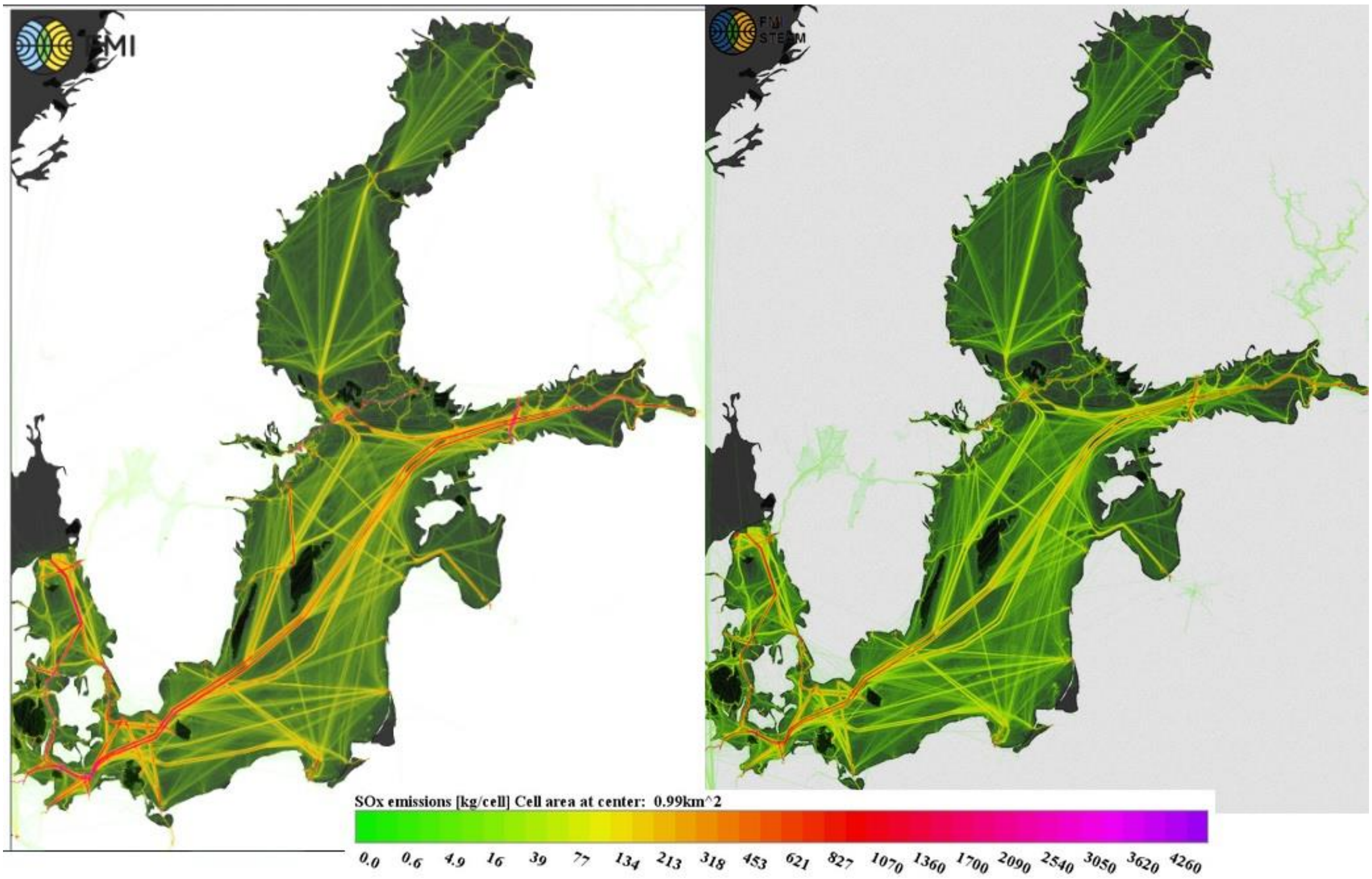
11 Annex II: SOx emissions Baltic 2014 & 2015, STEAM Model



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