

Marine Fuel Sulphur Limit Impact on Air Pollution

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ABSTRACT

The article presents calculation of Sulphur oxides percentage drop rate in marine industry recorded after 01.01.2020 when new limits, provided by International Maritime Organizations legislation, became effective. Ships' SO_x global emission was estimated and compared between 4th quarter 2019 and 1st quarter 2020. For more accurate estimation 3 seaside cities with big harbors were selected for statistical analysis. Noticeable SO_x decrease was observed. In one case the drop was at similar level to theoretical. There were found significant correlations between heavy fuel oil bunker and SO_x level in the air.

Keywords: Sulfur oxides, Marpol, SO_x limits, Ships emission, Exhaust gas.

Mathematics Subject Classification: 62-02

Journal of Economic Literature (JEL) Classification : C10, Q53

1. INTRODUCTION

According to the International Maritime Organization, in 2012, SO_x and NO_x emissions from the shipping industry accounted for 10–15% of global exhausts, compared to 3% of global CO₂ emissions [10]. As this is commonly recognized the gas emission harm environment and health. Especially it has been proven that SO_x have negative health impacts as premature mortality, lung cancer, asthma or heart attack [2], [11]. That is the reason why IMO enforces its sulphur emission cap. In accordance with Marpol Annex VI, Reg. 14 [5], from 1st January 2020 maximum allowable sulphur mass participation in any fuel oil used on board, shall not exceed 0,5 %. Before this date the worldwide limit except emission control areas (ECA) was 3,5%. The limits for global and ECA due the year can be found at Figure 1 [2].

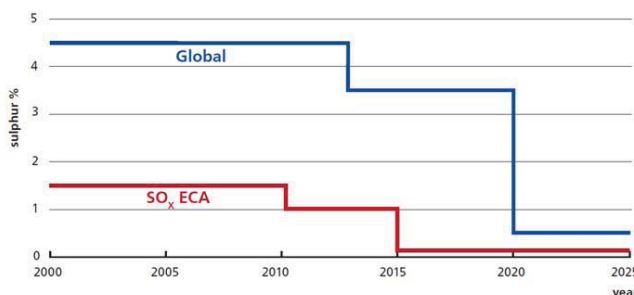


Figure 1. The amount of sulphur in the fuel limits, according to MARPOL Annex VI, Regulation 14.

According to the global sulphur cap 2020 after 01.01 the ship-owners had 4 mainstreams options to continue operating their ships. Use marine diesel oil (MDO) as main fuel, use very low sulphur fuel oil (VLSFO) which is up to 0,5% sulphur content instead of heavy fuel oil (HFO) up to 3,5% sulphur content, adopt the ship to LNG operation or perform the exhaust gas scrubber retrofit. As scrubber or LNG system require the expensive retrofit in a shipyard, use of MDO or VLSFO is costless beside tank washing, filters change, etc. Moreover, the MDO should be always more expensive than VLSFO. For the above economic reasons nowadays, the ships vast majority use VLSFO as main fuel. According to the review of maritime transport 2019 [16] in early 2019 total world fleet stood at 95402 ships with 1,97 billion dead-weight tons of capacity. Taking into account ships over 1000 GT the new amount was 51684. Based on DNV GL data, total number of LNG-fuel ships are close to 300 (excluding ships being on order). Total estimated number of ships equipped with exhaust gas scrubber is 4000. The circle diagram at figure 2 shows percentage comparison of data above.

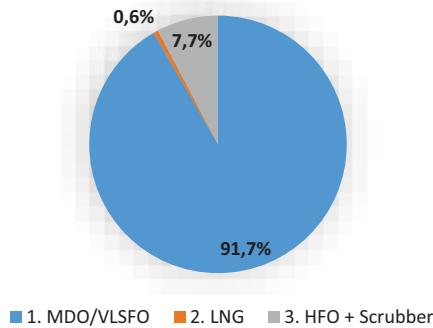


Figure 2. Percentage comparison of different ship fuels.

2. GLOBAL SO_x REDUCTION

The sulphur emission depends on sulphur content in fuel, which for LNG is less than 0,004% [9]. The scrubber operation using close loop Wartsila solution, gives 97,15 % reduction of SO_x which corresponds to reduction of fuel sulphur content from 3,5% to 0,1% [18]. Both of those emissions will be omitted in comparison to VLSFO ships. Let's assume more unprofitable option for the environment, that all ships except the LNG-fuel and equipped with scrubber use VLSFO instead HFO (avg. 2,5% sulphur content [10]). The consequence will be certainly bigger reduction rather than shows in Table 1. The mass of SO_x emitted by vessel m_{SO_x} [kg], could be calculated by multiplying fuel oil consumption m_{HFO} [tons] and sulphur content factor σ [kg/tons] [10].

$$m_{SO_x} = m_{HFO} \cdot \sigma = m_{HFO} \cdot \alpha \cdot S_{\%} \quad (1)$$

Where:

α – SO_x fixed factor = 20 [–]

$S_{\%}$ – Sulphur content in fuel [%]

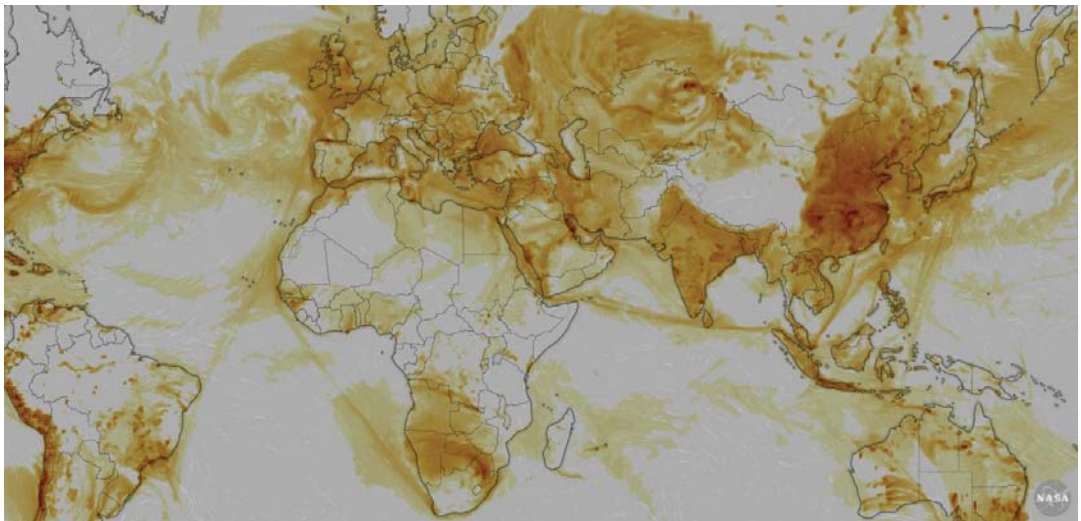
According S&P Global Platts Analytics estimated global bunkering of heavy fuel oil in early 2019 at 300 mln tons and dropped below 100 mln tons in early 2020. In same time the VLSFO demand, increased by 200 mln tons. Using formula (1) and the percentage share of HFO ships, estimated SO_x emission are shown in Table 1.

Table 1. Annual SO_x emission

Year	Early 2019	Early 2020	Reduction
Estimated SO _x annual emission	~ 13,8 mln tons	~ 2,8 mln tons	~ 80%

The approximate value of 80% obtains from formula 1, corresponds with more complex method from Tokuslu analyse of SO_x emission in Port of Eregli (Turkey). The ultimate reduction between 2019 and 2020 was estimated to 83% [13]. Another article from same author focus on Bosphorus Strait and Istanbul harbour [14]. The method for emission estimation based on the division ships on type and state (cruising, manoeuvring, harbour resting). According to this, special factors are added to equations. A very useful tool in comparison of sulphur oxides drop, could be a global map that shows SO₂ concentration in the air like www.windy.com. Data is gathered by NASA using unique instruments, mounted on satellites, such as Total Ozone Mapping Spectrometer (TOMS) or newer Ozone Monitoring Instrument (OMI). Figure 3 shows a map of SO₂ trails in the air for 06.05.2020. Sulphur dioxide shown on the map comes from all sources, such as volcanos, heavy industry factory, power plants and ships. It can be easily found that there are visible tracks at most common ship routes as Europe – South Africa, Sues – Malesia, China – Indonesia – Japan – Korea - Philippines. In compression at Figure 4 can be found map from same day that shows global ship traffic.

As www.windy.com doesn't provide historical data, it is impossible to compare the turn of the year 2020. Data from OMI can be found at another NASA site, but all monitoring sites mostly keep attention on volcanic region, which makes it unable to extract the ships SO₂ emission impact on the environment. Furthermore, Fisher [4] in his model shows the impact of the wind and humidity on sulphur dioxide long range transport. The result of this analyses causes that map below must to be treated with the highest caution.


Figure 3. The map with SO₂ concentration [8]*

****Maps are showed for academic purpose only and does not represent any accurate political or geographical area of any country.***

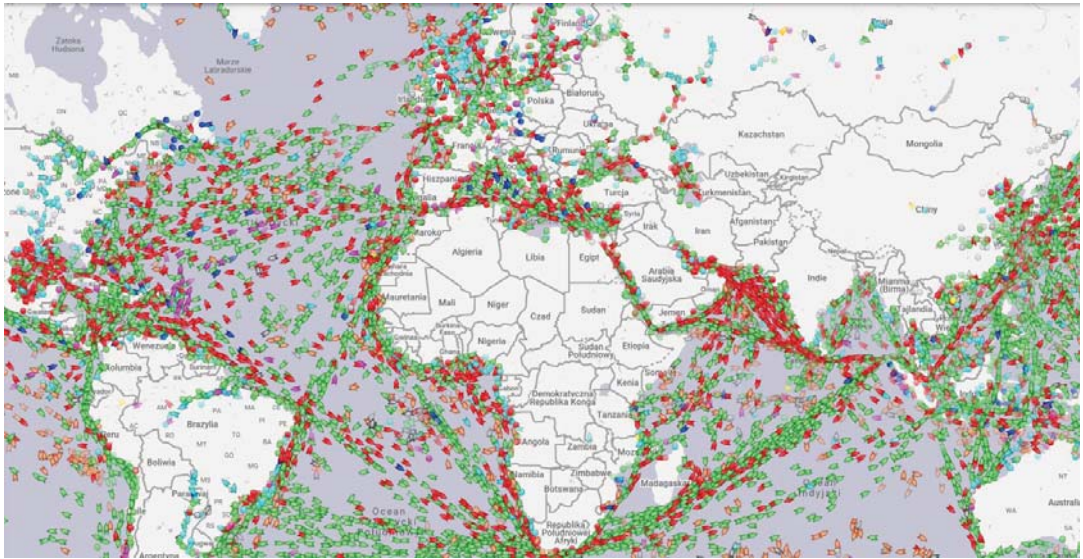


Figure 4. The map shows ships traffic [7]*

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3. LOCAL SO_x REDUCTION

For comparison the World Air Quality Index [www.waqi.info] will be used. It is non-profit project started in 2007, which gathers data from over 30.000 weather stations all over the world. Comparison will be based at three ports which were outside of ECA region, with significant marine traffic and without active volcano in the nearest area. Chosen ports were:

- 1) Cape Town
- 2) Singapore
- 3) Cadiz

All Sulphur dioxide data at WAQI site [17] are given in US EPA Air Quality Index (AQI) units. US AQI units are divided into six categories, corresponding to level of health concern. The AQI below 50 represent good air quality which corresponds to that up to 35 parts per billion SO₂ particles captured per hour. Details are presented at Table 2 [15].

Table 2. Air Quality Index according to US EPA standard.

SO ₂ [ppb] (record time)	AQI – value	AQI - category
0-35 (1 hour)	0-50	Good
36-75 (1 hour)	51-100	Moderate
76-185 (1 hour)	101-150	Unhealthy for Sensitive Groups
186-304 (1 hour)	151-200	Unhealthy
305-604 (24 hours)	201-300	Very Unhealthy
605-804 (24 hours)	301-400	Hazardous
805-1004 (24 hours)	401-500	Hazardous

For comparison of the data, a period of 7 months will be considered. September – November 2019 and January – April 2020. December was skipped, because the most of vessels already switched to new low sulphur fuel, as during Christmas time there is lower availability of marine onshore services. There were no visible differences between December and January. Table 3 shows monthly averages of SO_x AQI values for three chosen harbours. The primary data set contain one value per day. In last column percentage drop value was calculated as average AQI Sep-Nov '19 to Jan-Apr '20 ratio. All AQI values are considerably lower than 50, which represent the limit of good air quality category. However, Sulphur oxides could accumulate in the air due to weather condition, and after combining in cloud steam, cause the extremely harmful acid rains in entirely different place.

Table 3. Average SO_x US AQI units in different harbours at the end of 2019 and beginning of 2020.

	Sep '19	Oct '19	Nov '19	Jan '20	Feb '20	Mar '20	Apr '20	Avg. Sep-Nov '19	Avg. Jan-Apr '20	Drop
Cape Town	3,52	1,58	1,71	2,00	2,55	0,39	0,29	2,27	1,31	42,4%
Singapore	6,71	9,32	7,97	1,23	1,19	2,84	2,61	8,00	1,97	75,4%
Cadiz	0,94	1,71	2,55	2,29	0,87	0,35	1,13	1,73	1,16	32,9%

As Singapore characterised by the largest decrease in SO_x concentration from selected cities, the additional Figure 5 shows a bar graph with monthly averages AQI value for longer time period (April 2019 – April 2020). There is visible difference between the period from April 2019 to November 2019 where AQI value was between 5,8 to 9,3 and from December 2019 to April 2020 with AQI reaching 1,3 ÷ 2,7. The mean in first high AQI period was 7,33 and in low period 1,95. Ratio of those values gives 73,4% average SO_x drop.

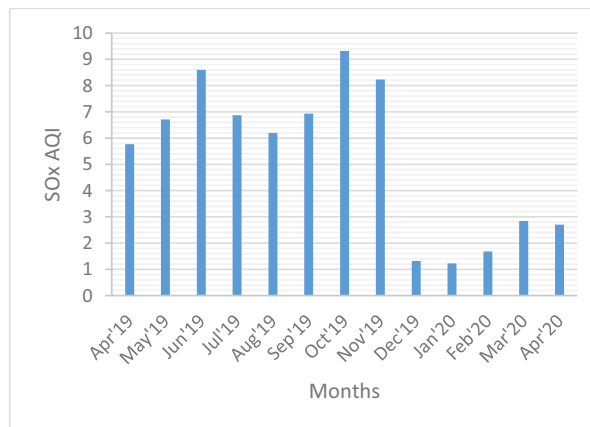


Figure 5. A bar graph with monthly averages of AQI in south Singapore.

SO_x reduction in harbour should correspond to the sales reduction of HFO. The Figure 6 shows total monthly bunkering amount in thousand tons of heavy fuel oil 180cSt, 380cSt and 500cSt in Singapore. Sales fuel amount data is gathered by Maritime and Port Authority of Singapore [6].

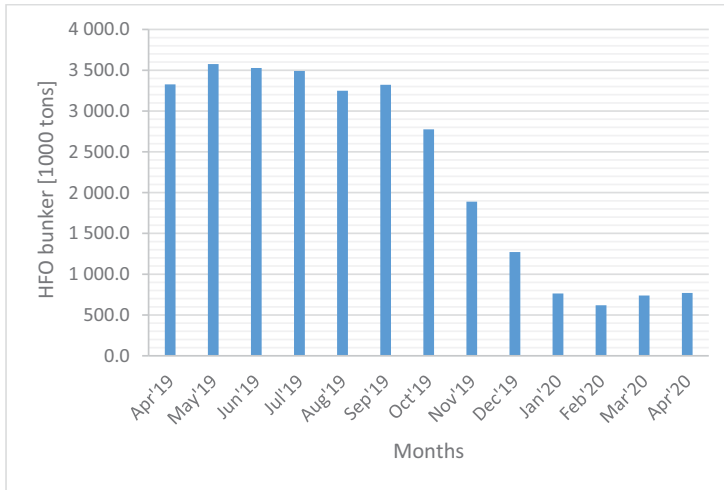


Figure 6. A bar graph with monthly MFO bunkering in Singapore.

For comparison purpose, charts time range at Figure 5 and Figure 6 are the same. The H_0 null statistical hypothesis was formulated “There is direct correlation between amount of bunker fuel and AQI SO_x value in Singapore”. Figure 7 shows scatterplot between amount of bunker HFO and value of AQI. The marked on chart confidence level is 0,95. As dependent variable has been chosen AQI value.

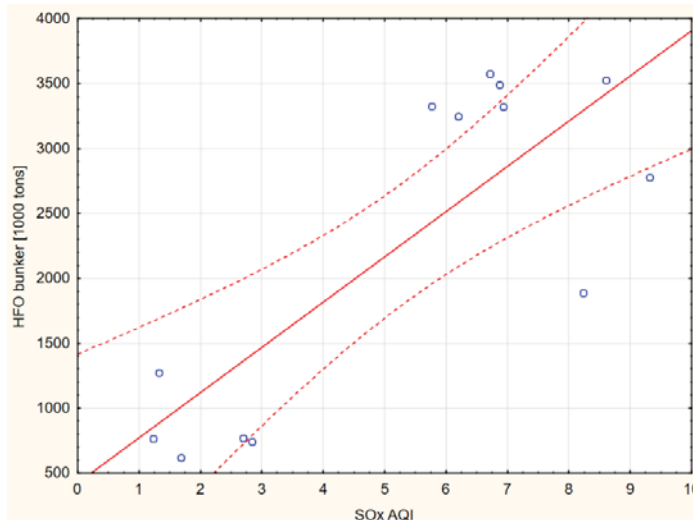


Figure 7. Scatterplot of bunkers HFO and SO_x AQI values.

The correlation analysis where done in statistical analysis software STATISTICA. The significant level $\alpha = 0,05$. The coefficient of determination $R^2 = 0,657$, which is statistically significant as $p\text{-value} = 0,0008$. As a result, the H_1 alternative hypothesis “There are no correlation between amount of bunker fuel and AQI SO_x value in Singapore” was rejected. The R^2 value, in this case, can be interpreted as, the drop of HFO bunkering amount in Singapore, explains 65,7 % of SO_x reduction in this area [12].

4. SUMMARY AND CONCLUSION

Conclusion from a simple calculation, such as the one presented, have to be analysed with caution. There is visible impact for SO_x reduction over 2019/2020. In particular this cut is apparent in Singapore reaching 73,4%. This value is close to the theoretical 80%. The observation made in Cape Town and Cadiz show only ~50% of theoretical sulphur oxides drop. There are correlations between HFO sales and SO_x level. Certainly, some part of noticed reduction are owed to Marpol Convention and uses of low sulphur fuels and exhaust gas scrubbers on board. Although it is hard to predict if all this drop is related to ships. There are many unknowns as e.g. specification of heavy industry working. Due some technological process there can be produced much more sulphate oxides than on average day. Also, volcanoes should be considered as disruption, as ash with sulphur can be carried thousands of kilometres with the wind. Furthermore sulphur oxides could react with some chemical compounds in air/rain and deposit in ground or seas [1].

Notwithstanding impact of Marpol sulphur limits are observed, so imposed by law global pollution limits are effective method for the future environment saving without sulphur oxides and acid rains.

5. REFERENCES

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