CO₂ and sulphur emissions from the shipping industry

CO₂ emissions related to the fuel switch in the shipping industry in Northern Europe.

October 2016
Abstract

A majority of the shipping industry in the Baltic Sea, the North Sea and the English Channel (SECA) have switched fuel as of January 2015 to comply with the new sulphur emission regulation. Gasoil or marine diesel are, post the implementation of the directive, predominant over the previously popular low sulphur fuel oil. As a consequence, airborne sulphur emissions has decreased drastically and several studies indicate only minor changes in greenhouse gas (GHG) emissions as a result of the fuel switch. This report disputes such claims and instead argues that the increase in indirect emissions of CO2 is severely underestimated, with a theoretical increase of 112 million tonnes of CO2 and statistical support for 93 million tonnes of CO2 per annum caused by the fuel switch in the European SECA region. It is important to note that this increase in overall emissions does not stand in contrast to reduced tailpipe emissions from the shipping industry.

The increase in CO2 emissions can be detected when observing refinery crude oil intake, pre and post the new regulation was implemented, that has increased as a consequence of the shipping industry demand switch from a low value to a high value oil product. Increased crude oil intake is in turn equivalent to increased emissions of CO2 if the share of oil products being stored or used for other purposes than combustion is constant.

During the period November 2012 to November 2015, fuel oil price averaged between 60% and 80% of crude oil whereas price for gasoil ranged between 110% and 180% to that of crude oil. When assessing CO2 emissions from sub products in such a system, low value products often are attributed with an unjustifiable share of CO2 emissions. When assessing effects of the fuel switch in the SECA region, where an entire industry has switched fuel over night, overlooking how a demand shift affects demand for crude oil, is a fallacy.

Shipping companies that have installed scrubbers, an exhaust gas cleaning device, can use fuel oil and still comply with the stricter sulphur regulation and therefore do not contribute to increased indirect CO2 emissions. Incentives for reducing CO2 should therefore be directed to increase the use of scrubbers in the maritime industry. Preliminary estimates suggest that reducing CO2 emissions with the use of scrubbers could have a very low or negative cost and are most likely on par with the European emission trading system.
Foreword and acknowledgements

I want to thank the following organizations for contributing to the performance of this study:

- **EGCSA** – the Exhaust Gas Cleaning Systems Association
- **Smurfit Kappa** – a global packaging company
- **SveMin** – Swedish Association of Mines, Mineral and Metal Producers
- The **Swedish Confederation of Enterprise**
- **TT-Line**
- **Wagenborg Shipping Sweden AB**

**TT-Line** is a modern shipping company operating ferry routes across the Baltic Sea between Germany and Sweden as well as between Poland and Sweden. With six ro-ro passenger ferries and up to 23 daily departures and up to 150 departures a week, TT-Line connects the largest German Baltic ports Travemünde and Rostock as well as the Polish port of Świnoujście with Trelleborg in southern Sweden. TT-Line is the market leader in passenger and freight traffic between Germany and Sweden. The ferry connection between these two countries exists since 1962.

TT-Line's technical innovations and environmental management has received several awards. TT-Line developed its 'Green Bridge Concept' and achieved further reduction of emissions of harmful substances with the installation of diesel electric propulsion systems since 1995. In order to meet the IMO's (International Maritime Organization) requirements to reduce air pollution by ships, in force since the beginning of 2015, TT-Line installed state of the art exhaust gas cleaning systems, so-called 'scrubbers', on its ferries "Nils Holgersson" and "Nils Dacke". Besides removing a good part of particles from the exhaust gas by the scrubbers, sulphur oxide emissions are reduced to at least a level corresponding to a sulphur content in fuel of maximum 0.1%. Other vessels in the fleet are operated today with compliant low sulphur fuel.

The Exhaust Gas Cleaning Systems Association (EGCSA) was established in 2008 to help create a sustainable operating environment within the marine and energy industry sectors for exhaust gas cleaning system technologies, providing clarity and a rational voice for those companies interested in reducing marine exhaust gas emissions. EGCSA offers impartial technical information, advice and opinion on the many current and future issues and challenges related to emissions reduction and marine exhaust gas cleaning systems. Member companies of the EGCSA are involved in the development, design and final installed configuration and design approval and acceptance of turnkey exhaust gas cleaning systems to meet the current and future emissions regulations of IMO and, where applicable, additional regulations introduced by regional and national authorities.

The **Confederation of Swedish Enterprise** (Svenskt Näringsliv) is Sweden's largest and most influential business federation representing 49 member organizations and 60 000 member companies with over 1.6 million employees. Svenskt Näringsliv has an active role in investigating the effects of the European Sulphur Directive by providing a forum of discussion and by supporting extensive analysis of the effects for Swedish companies, transport system and environment.
## 1. INTRODUCTION

## 2. BACKGROUND

## 3. EMISSIONS AND SHIPPING FUEL USE

## 4. REFINING

### 4.1. REFINERS RESPONSE TO FUEL SHIFT IN SHIPPING INDUSTRY

### 4.2. NEW TECHNOLOGY IN REFINERIES

### 4.3. CRUDE OIL QUALITY AND ORIGIN

### 4.4. OIL PRODUCT SUPPLY

### 4.5. REFINERY THROUGHPUT AND ADDED CO2 EMISSIONS

### 4.6. THEORETICAL ADDED CO2 EMISSIONS RESULTING FROM THE FUEL SWITCH

### 4.7. SCRUBBERS AND CO2 EMISSIONS

## 5. DISCUSSION

### 5.1. MITIGATING CO2 EMISSIONS FROM THE SHIPPING FUEL SWITCH

### 5.2. COST FOR CO2-REDUCTION BY THE USE OF SCRUBBERS

### 5.3. THE 0.5 % SULPHUR CAP FOR INTERNATIONAL SHIPPING

## 6. REFERENCES
1. Introduction

The purpose of this study is to assess changes in emissions of CO2 as a result of the sulphur emission regulation in the maritime industry in northern Europe. Several public and scientific reports with the objective to analyse the effects of the fuel switch have not indicated increased CO2 emissions as a result of reduced sulphur emission limits that went into effect in January 2015.

This report provides an alternative view to what has happened to overall CO2 emissions and is supported by statistics from the Eurostat. The conclusion is that emissions of CO2 has increased drastically and also proposes how this increase can be mitigated.

The study further sets out to spark a debate around to what extent high and low valued fuels can be said to affect refinery intake of crude oil that ultimately, contrary to demand for any single oil product, is linked to emissions of CO2. Presently, emissions from oil products are assessed separately regardless of price and how it affects demand for crude oil. This way of estimating CO2 emissions is valid as long as demand does not shift between oil products. Dramatic shifts in demand for oil products, like in the case with the sulphur regulation as of 2015, are very uncommon. However if a fuel switch takes place, assuming no change in demand for crude oil risks concealing increases/decreases of CO2 to decision makers thus resulting in a flawed policy for reduction of CO2 emissions.

2. Background

In January 2015, an amendment to the regulatory framework in the EU for marine fuel was taken into effect for the Baltic Sea, the North Sea and the English Channel (area referred to as SECA see Figure 1). This came into force parallel to an amendment to MARPOL Annex VI on international level, also addressing regional requirements for SECA. European directive 2012/33/EU, the so-called sulphur directive, was first introduced to mirror MARPOL Annex VI on a European legislative level. In some areas, directive 2012/33/EU even goes beyond MARPOL. Amendments to MARPOL Annex VI were adopted by the International Maritime Organization in 2008. The main purpose was to reduce air borne sulphur oxide emissions that can be linked to respiratory disease. The new framework for marine fuel stipulated by both legislations, post 1st of January 2015, limits fuel sulphur content to 0,1 weight-% for all ships entering the designated area, regardless of flag, whereas the previous limit was 1 weight-%.

---

1 European Commission, Directive 2012/33/EU.
The fuel sulphur content is not, since it generally does not add to the heat value of the fuel, correlated to emissions of CO2. Simply switching fuel should therefore only have minor effects on overall CO2 emissions from a “tank-to-propeller” perspective, i.e. the energy required to propel ships remains unchanged.

Before the amended sulphur regulation, shipping in SECA predominantly used low sulphur heavy fuel oil (LSHFO) due to its low price relative to other oil products. Fuel oil has to be kept at certain temperatures to remain in liquid form and is therefore unsuitable for use except in dedicated applications, which is one reason to the relative low price.

According to a study by the Swedish governmental agency of Transport Analysis\(^2\), most vessels post January 2015 has switched to low sulphur fuels, primarily marine diesel oil (MDO) which is a blend of fuel oil and gasoil or marine gas oil (MGO) typically with a sulphur content of under 50 ppm, in order to comply with the new regulation. The study does not highlight other consequences to the new regulation, like increased use of scrubbers or new technology in the refining industry to reform fuel oil into gasoil.

3. Emissions and shipping fuel use

Studies post the implementation of the new regulation indicate that sulphur emissions from the marine industry have decreased drastically in SECA. There is also a consensual conclusion that there have been only minor changes in CO2 emissions. Some assessments are based on a methodology called accounting Life Cycle Analysis (aLCA) that adds emissions from a products life cycle, starting by the extraction of crude oil all the way to the combustion of the oil product. The methodology adds emissions for sub-products and necessary refining processes, as well as direct emissions resulting from transporting and end-using.

Emissions can also be assessed from a top-down perspective, for example by assuming that a fixed share of all oil products is combusted. If making such assumptions it is unnecessary to assess each oil product individually. If the refined crude oil share that does not get combusted (for instance products that is used for plastics and asphalt production) is constant or quantifiable, then crude oil extraction rates or crude oil refinery intake provides good correlation with CO2 emissions.

In periods of rapid transition, fuels may be stored in wait of higher prices. This could reduce the accuracy in assessing emissions from a top-down perspective since the oil product is not combusted at the same pace as prior to the system shift. However since capacity to store oil products is limited the system will obtain a steady state once storage capacity is full.

CO2 emissions from crude oil range between 2,940- 3,212 grams of CO2 per gram of crude oil3. CO2 emissions for fuel oil are 3,114 grams per gram and 3,206 grams CO2 per gram marine diesel oil according to an LCA study by the International Maritime Organization, IMO. The study indicates stagnant emissions of CO2 from shipping over the period 2007-2012, see Figure 2.

![Figure 2](source: Third IMO GHG study 20144).

The consultancy company SWECO estimated5 annual shipping fuel use in the European SECA, in 2011, to 20 million tonnes corresponding to between 62,3- 64,1 million tonnes of CO2 emissions.

---

Prior to the implementation of the sulphur directive, there were concerns that goods might shift transport modes resulting in lower energy efficiency per tonne kilometre, but any major shift in transport modes has not been detected according to a report from the Swedish Traffic Analysis. One important reason to this is the relative low level of oil prices, and hence fuel prices prevailing since the end of 2014.

A study of greenhouse gas emissions published in Elsevier journal for Transportation Research Part D in 2014, is comparing alternative marine propulsion systems. Three of them are listed below:

1) Heavy fuel oil (HFO)
2) HFO combined with exhaust gas cleaning combined with a scrubber
3) Marine gasoil (MGO)

The study concludes that alternative 2 has slightly higher GHG emissions than alternative 1 which has slightly higher emissions than alternative 3. In other words, CO₂ emissions from ships running on gasoil are lower compared to fuel oil (with or without scrubbers). The approach of the study is so called consequential Life Cycle Analysis (cLCA), which sets out to assess changes in CO₂ as a consequence to a certain decision, in this case the potential fuel shift taking place when introducing the sulphur directive in SECA. The study concludes that GHG emissions vary less than 8% between the three alternatives compared. The study does not mention changes in refinery operations other than added GHG from desulphurization of gasoil.

A study from the Finnish Meteorological Institute concludes that direct CO₂ emissions in the Baltic Sea has increased by 5.6% in 2015 compared to 2014 based on analysis from AIS transponders. The study does not address indirect effects and focus on only tailpipe emissions.

4. Refining

The term crude oil covers almost as many different qualities as there are oil fields. A few crude oil qualities are used as benchmark and other crude oils are priced in relation. Important for the evaluation of a crude oil quality is the content of sulphur and phosphor as well as density (that in turn decides the oil product shares). Next the various sub products may differ in terms of sulphur content, pour point, flash point etc.

In order to use each product as efficiently as possible they have to be separated from each other, which is done by refining. The most fundamental process in a refinery is distillation that separates oil

---

7 Transportation Research Part D. Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels, 2014. Brynolf, Fridell, Magnusson and Andersson.
products according to condensation temperature. If only separating oil products by distillation the share of high value products will be low. To increase revenue refineries add processes that increase the share of high value products and minimize share of low value products. Fuel oil has a historic low value compared to crude oil that in turn has a low value compared to gasoil. Refiners will therefore have to balance output of fuel oil with positive margins from high value oil products.

Figure 3 displays average marine bunker price for the ports of Singapore, Rotterdam, Fujairah and Houston for MGO and IFO380. It shows the relative price difference for fuel oil (IFO380, black line, left axis) and Marine Gasoil (MGO, blue line, left axis) compared to crude oil (Brent, green line, right axis) for the period Nov 2012 to Nov 2015.

![Figure 3](image)


Note that fuel oil price has been averaging between 60-80% of crude oil price in the period November 2012 October 2015 where at the same period price for gasoil ranged between 110-180% to that of crude oil which is a clear indicator of a high and low value sub product system.

4.1. Refiners response to fuel shift in shipping industry

Marine fuel can be classified according to density from lightest to heaviest: Marine Gasoil (MGO), Marine Diesel Oil (MDO), Intermediate Fuel Oil (IFO), Marine Fuel Oil (MFO) and Heavy Fuel Oil (HFO). Sulphur removal in refineries is expensive, both in terms of capital investment and running cost since desulphurization requires considerable amounts of hydrogen, typically obtained from natural gas. This in turn correlates sulphur removal to direct CO2 emissions. Sulphur removal with hydrogen is typically performed for vacuum gasoil or lighter products; it is not done for heavy fuel oil. Lowering sulphur content in heavy fuel requires blending with low sulphur products while ensuring that the blend meets all necessary specifications.

The report from the Swedish Traffic Analysis indicates that the shipping industry have predominantly switched fuel from LSHFO to MDO as of January 2015. This has triggered a response
from refiners that already were maximizing the gasoil fraction and minimizing the fuel oil fraction. To adapt to the new demand, most refiners had the following options closest at hand:

1) Install/invest in **technology** that increases the gasoil to fuel oil output ratio.
2) **Switch crude oil quality** to a type that contains higher share of the desired fractions.
3) **Increase** overall refinery **utilization rate** with unchanged product shares.

Option 1 might mean a reduction of CO2 even though it may increase CO2 for desulphurizing the gasoil fraction since adding processing steps in imposes increased energy consumption. Note that refineries operating equipment that can desulphur fuel oil prior to 2015 are expected to already maximize their gasoil output and cannot contribute to increased gasoil to fuel oil output ratio post 2015.

Option 2 is possible but would assume that supply of a crude oil quality that matches the new demand of refineries can be supplied post January 2015.

Option 3 requires that refinery utilization was intentionally below 100 % pre January 2015. Further a requirement is that the oil product output mix provides a beneficial economy to the refiners, i.e. good refinery margins.

Refinery response and options will be analysed and discussed further in chapter 4.2-4.6.

### 4.2. New technology in refineries

An advanced refinery has several processes that allow for transformation of low valued products into higher valued products. Two important processes in European refineries are the fluid catalytic cracking and hydrocracking. Hydrocracking exists in different forms but a modern version called slurry hydrocracking allows for almost complete transformation of fuel oil into gasoil. This far, there is only a single refinery in Europe that uses this technology. A more widely used conversion method is the vacuum gasoil hydrocracker often combined with a viscous transformation unit (VIS-breaker). Such a unit allows for transformation of vacuum gasoil (VGO) into gasoil or diesel. The fuel oil residue, after the VGO is separated, is called heavy fuel oil (HFO) and typically has a high sulphur content that is very hard to remove.

According to the European oil branch organisation CONCAWE\(^9\), there has been only minor modifications in the European refinery industry during 2014 and 2015 that allows for more extensive desulphurization. It can therefore be assumed that the ratio gasoil to fuel oil have not been altered after the sulphur directive was implemented, which is supported by production data from two European refining companies: Neste Oil and TOTAL. Their production shares are listed in tables 1 and 2.

---

\(^9\) CONCAWE, 2014. Presentation by Alan Reid at a seminar in Stockholm.
Table 1  Neste Oils share of in-house production [%]

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Gasoline</th>
<th>Fuel oil</th>
<th>Other</th>
<th>Diesel share</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>38</td>
<td>27</td>
<td>7</td>
<td>17</td>
<td>43 %</td>
</tr>
<tr>
<td>2013</td>
<td>37</td>
<td>26</td>
<td>8</td>
<td>17</td>
<td>42 %</td>
</tr>
<tr>
<td>2014</td>
<td>35</td>
<td>27</td>
<td>7</td>
<td>16</td>
<td>41 %</td>
</tr>
<tr>
<td>2015</td>
<td>34</td>
<td>26</td>
<td>8</td>
<td>16</td>
<td>40 %</td>
</tr>
</tbody>
</table>

*Source: Neste Oil Financial Statement in 2015 and 2013.*

Neste Oil has two petroleum refineries in Finland that, by their location with long distances in SECA regulated waters are extra affected by the marine fuel switch. In spite of this fact, the diesel share has been following a downward trend during 2012 to 2015. Table 1 is based only on the diesel share using crude oil as feedstock, i.e. no renewable diesel is included.

Table 2  TOTALs product share of own refineries [%]

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Gasoline</th>
<th>Fuel oil</th>
<th>Other</th>
<th>Diesel share</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>42</td>
<td>20</td>
<td>9</td>
<td>28</td>
<td>42 %</td>
</tr>
<tr>
<td>2013</td>
<td>44</td>
<td>20</td>
<td>8</td>
<td>28</td>
<td>44 %</td>
</tr>
<tr>
<td>2014</td>
<td>45</td>
<td>20</td>
<td>8</td>
<td>27</td>
<td>45 %</td>
</tr>
<tr>
<td>2015</td>
<td>44</td>
<td>19</td>
<td>7</td>
<td>30</td>
<td>44 %</td>
</tr>
</tbody>
</table>

*Source: TOTALs Financial Statement in 2015 and 2013.*

TOTAL operates 12 refineries in Europe. The production data show a slight increase in diesel shares for the whole period but a decrease between 2014 and 2015. The production data does not support that output shares for gasoil and fuel oil has not been altered in 2015.

A refinery that does possess, but do not utilize, the potential to transform fuel oil to gasoil would most likely be operating financially sup-optimal, especially considering the increased demand for gasoil compared to fuel oil since January 2015. This supports the hypothesis that refiners where already maximizing output ratio of gasoil compared to fuel oil prior to January 2015.
4.3. Crude oil quality and origin

Crude oil contains varying shares of oil products and substances depending on type of origin of biological material and how the oil has been imbedded and stored. If crude oil is refined in a basic refinery, the oil product output ratio is less likely to match the oil products demanded. Figure 4 provides typical oil product shares for five different types of crude oil qualities divided according to origin and also the European demand from all sectors.

![Bar chart showing oil product shares for five different crude oil qualities and European demand.]

Source: CONCAWE, 2015.

A potential response to the shipping fuel switch could be to switch crude oil quality, for instance from Brent to Nigerian. CO2 emissions would not increase as long as supply of Nigerian oil could meet the new demand.

4.4. Oil product supply

Output of oil products is correlated with the trend of the decreasing number of European refineries that has been on-going for over a decade. Oil product output from European refineries is published through the European Commission database Eurostat. Russian refineries are not part of the statistics but in general tend to have a lower output of high value products compared to the European refinery average.
Figure 5 shows output of fuel oil and gasoil from refineries in or near the SECA region (refineries in Belgium, Denmark, Estonia, Finland, France, Germany, Latvia, Lithuania, the Netherlands, Norway, Poland, Sweden and the United Kingdom) from January 2012 to July 2016. No major shift in output ratio is detectable and the two curves appear well correlated. The ratio of gasoil to fuel oil would likely have increased along with the demand switch if refineries did possess spare capacity to produce more gasoil on behalf of fuel oil. This would also hold true if refiners should switch crude oil type in favour of a quality containing a larger gasoil share. Assuming that gasoil to fuel oil ratio is fixed between 2014 and 2015 is thereby supported by statistics.

Advanced refineries with a surplus upgrade potential of VGO does have the option of buying straight run fuel oil or VGO from less advanced refineries. This can explain monthly variations in gasoil output visible in Figure 4.

4.5. Refinery throughput and added CO2 emissions

According to CONCAWE, the European crude distillation capacity dropped by more than 29 % during the period 1983-2013. The number of refineries in the same period decreased from 130 to 82. Among the still operative refineries, only a minority operate at maximum capacity. A possible response from refiners to a shift in demand from fuel oil to gasoil could therefore be to increase refinery utilization rates resulting in added output of all oil products. In principal, such increased utilization would be more beneficial to refiners the lower the refinery output ratio of fuel oil compared to gasoil. According to tables 1 and 2 this ratio varies between 1/4 and 1/6 for Neste and TOTAL.
Statistical data of refinery crude oil intake in the SECA region is plotted in Figure 6.

**Figure 6**

**Monthly crude oil refinery intake - SECA region**

Two trend lines are added in Figure 6, one covering the period January 2012 until October 2014 (blue dotted) and one for the period November 2014 to July 2016 (red dotted). The blue trend line has been extended to make it comparable with the trend line for the second period. In July 2016, the difference between the two lines was 2.65 million metric tonnes of crude oil per month. The trend shift coincides with the introduction of the sulphur directive. Increased refinery crude oil intake of 2.65 million metric tonnes per month corresponds to 32 million tonnes of crude oil and is equivalent to 93 million tonnes of CO2 (2.94 grams CO2 per gram crude oil) in added emissions.

$$2.65 \times 12 \times 2.94 = 93 \text{ million tonnes of CO2}$$

Utilizing 32 million tonnes of crude in a refinery with output shares matching those provided in table 2 would correspond to 14 million tonnes of gasoil. Since the fuel usage for shipping in SECA was estimated to 20 million tonnes there is a deficit of 6 million tonnes of fuel (assuming all shipping switching from fuel oil to gasoil) or 5 million tonnes taking into account higher heat value of gasoil\(^\text{10}\).

Oil product output arising from the fuel switch are assumed to be fully combusted, that is there are no oil products being used as raw material for asphalt or plastics production. Also, oil products are not assumed to substitute other energy sources thereby resulting in substitution effects.

---

\(^{10}\) Preem product information, 2012. Heat values: IFO 380 - 11.3 kWh/kg. Gasoil - 11.9 kWh/kg.
The time intervals in which ships bunker vary but typically shipping fuel is purchased at least a full month ahead of usage. The impact of stricter sulphur regulation in terms of increased demand for low sulphur shipping fuel could therefore be expected before January 2015 and is why trends are observed pre/post October 2014.

4.6. Theoretical added CO2 emissions resulting from the fuel switch

CO2 emissions caused by the marine fuel switch can be calculated under the following assumptions:

- Refinery oil product output is combusted and transformed into CO2 both prior and post the sulphur directive got implemented. Oil products used as raw material, for example asphalt and plastics, are disregarded i.e. all products leaving refineries are combusted.
- Net storing of oil products is assumed at the same levels as prior to the new sulphur regulation, i.e. assuming the perspective is that of a steady state system.
- Refineries in SECA use the same crude oil quality as prior to the fuel switch.
- Refineries inside SECA supplies oil products to match demand, i.e. increased demand of gasoil will be met by refineries in SECA, not by imports. Refineries in SECA are maximizing gasoil output shares prior and post the implementation of the sulphur directive and there are no additions in process steps in the refineries.

The CO2 emission increase can be calculated:

1) Crude oil emits 2.940· 3.212 grams of CO2 per gram crude oil\(^ {11}\) combusted, not including emissions arising in the crude oil value chain. Fuel oil emits 3.114 g CO2 per gram fuel oil.
2) The shipping industry in SECA consumes fuel at a yearly rate of 20 million tonnes of fuel oil pre the implementation of the sulphur directive and 19 million tonnes of gasoil post the implementation of the sulphur directive\(^ {12}\).
3) Refinery output share of gasoil for a SECA refinery is assumed at 45 % (high estimate) and 9% for fuel oil (high estimate). The additional 19 million tonnes of fuel oil is considered a surplus product and therefore CO2 emissions are subtracted from the increase arising from increased crude oil throughput. This is a precaution in order not to overestimate the increase in emissions, for instance if the fuel oil surplus should not be combusted.

Theoretically, a lower limit to increased emissions is provided by:

\[
\frac{19 \times 10^6 \times 2.940}{0.45} - \frac{19 \times 10^6 \times 0.09 \times 3.114}{0.45} = 112 \text{ million tonnes of CO2}
\]

The estimate of added emissions of 112 million tonnes of CO2 (low estimate) would correspond to 0.33 % of global CO2 emissions of 2012.

\(^ {11}\) World Nuclear association, 2010.
4.7. **Scrubbers and CO2 emissions**

A scrubber is a device that captures sulphur emissions from exhaust gases thereby preventing it from reaching the atmosphere. A scrubber enables the use of high sulphur fuel in the SECA region and prevents increased indirect CO2 emissions. Scrubber extra weight and space increases energy consumption at the same time as increased dead weight will reduce cargo capacity causing direct CO2 emissions to increase slightly.

There are several types of scrubbers that offer different benefits:

- Dry scrubbers.
- Closed and open loop scrubbers.
- Hybrids.

Dry scrubbers are based on exhaust gases passing through a layer of granulate that has to be emptied and refilled at timely intervals. Open loop scrubbers capture sulphur from exhaust gases using either salinity from seawater or chemicals then return all fluids, along with the captured sulphur, to the sea. Closed loop scrubbers store the washing fluids along with the sulphur in tanks that have to be emptied regularly. Hybrids are a combination of open loop and closed loop.

By using fuel oil combined with a scrubber instead of switching fuel to gasoil, the increased refinery crude oil intake will not take place. Scrubbers thereby provide an indirect reduction of CO2 emissions. Prior to the implementation of the sulphur directive, the European Union offered support schemes for testing and developing scrubber technology as they were considered not fully commercial technology. Post the implementation of the sulphur directive there is no longer such support schemes.
5. Discussion

Statistics from Eurostat supports that refineries have increased crude oil intake during the period Nov 2014-July 2016 compared to the period Jan 2012-Oct 2014. The increase coincides with the implementation of the sulphur directive and thereby also the hypothesis of this study but to what extent could the shift in refinery behaviour be linked to other factors? Would refineries have increased crude oil intake if the sulphur directive had not been implemented and if so, to what extent? Is increased refinery crude oil utilization merely a response to improved refinery margins that just happen to correlate with increased demand for gasoil? This report does not provide proof that increased refinery utilization is a causality of increased demand for gasoil but concludes that the correlation is hard to dispute combined with standard market fundamentals - refineries were already maximizing gasoil shares prior to the implementation of the sulphur directive. Turning the question around: why would a refinery that has the ability to increase gasoil output (on behalf of fuel oil output) without increasing crude oil throughput, not already have done so? Not increasing output shares of a profitable product would be irrational.

5.1. Mitigating CO2 emissions from the shipping fuel switch

A technology installation that reduces GHG emissions is qualificable for governmental or European support measures. Some support systems prioritize according to the highest CO2 emission reduction per fiscal unit, as is the case with the Swedish support scheme – “Klimatklivet” (freely translated the Climate Step). The maritime industry is not part of the emission trading system nor is shipping fuel subject to GHG taxation due to its international nature. However if costs for mitigating CO2 emissions are lower compared to best practice measures in other sectors and the GHG reduction can be scientifically supported, such measures would be unwise to overlook.

Comparing the cost for CO2 emission reduction through the use of scrubbers to other forms of measures must be further analysed by authorities that govern such steering tools and could be a suitable exercise to follow this study. Indicative calculations suggest that scrubbers offer a total cost per CO2 reduction on par with the European emission trading system (ETS), which in of May 2016 cost less than 6 € per metric tonne of CO2. Since several shipping companies have installed scrubbers without being awarded any support measures, the cost for mitigating CO2 by the use of scrubbers could even be negative. Measures that offer negative cost falls into the definition of low hanging fruits and is the fastest way to provide reductions in GHG emissions.
5.2. Cost for CO2-reduction by the use of scrubbers

According to a report by SWECO\textsuperscript{13}, 14,000 ships are active in the SECA region per day. Out of those, 2,200 operate inside SECA on a daily basis and 2,600 operate inside SECA about half of their yearly operative time. The remaining 9,200 ships operate in SECA only on occasional basis.

Assuming that a ship can be equipped with a scrubber at a cost of 8 million € and that the installation will have a life span of 20 years and that all vessels in total consume 20 million tonnes of fuel oil (instead of gasoil) per year, the cost per emission reduction can be calculated as follows:

\[
\text{\frac{14,000 \text{ vessels} \times 8 \text{ million } € \text{ per ship}}{20 \text{ years lifespan} \times 112 \text{ million tonnes } CO_2}} = \text{50 } € \text{ per tonne of } CO_2 \text{ mitigated}
\]

The price benefit of being able to use fuel oil instead of gasoil has already driven shipping companies to install scrubbers, indicating that the measure can be economically motivated without further incentives. It is also worth noting that the cost for emission reduction for the 2,200 of the ships that operate in SECA at a daily basis would be considerably lower than in the example above. With regards to fuel consumption, ships that operate inside SECA on a daily basis use a proportionally larger share per ship and year compared to ships that only occasionally enter SECA. Ships that occasionally enter the SECA will likely not provide a low cost per CO2 emission reduction from the use of scrubber.

Supporting scrubbers through governmental incentives does not require imposing GHG tax on shipping fuel, which would be incompatible with the international nature of the shipping industry. Instead this could be incentivized through reduced port or route fees for ships that use high sulphur fuel oil but does not emit sulphur in the exhaust gases. Such fees already benefit ships that meet certain environmental standards, similar to support systems for the use of renewable fuels.

Yet another way of support is to incentivize harbour infrastructure for removing and supplying ships with the necessary logistics chains for waste, chemicals and other consumables that are required to operate scrubbers. Currently, only a small share of all Swedish harbours has invested in such infrastructure, which is an important parameter for a shipping company when making decisions about a possible scrubber installation.

Last but equally important, Swedish authorities and politicians supported the sulphur directive with the argument that this would give our domestic shipping industry an opportunity to lead a good example of how to adapt to stricter sulphur regulation. From the perspective of this report, with an increase in CO2 emissions, using scrubbers and thereby not contributing to added CO2 would be a smart way to lead by example. Support systems should be adapted accordingly.

\textsuperscript{13} SWECO, 2012. \textit{Consequences of the Sulphur Directive}.
5.3. The 0.5 % sulphur cap for international shipping

The straight run fuel oil obtained from a basic refinery contains varying shares of gasoil (labelled “fuel oil” in figure 5). Advanced refineries use vacuum distillation units to separate VGO from HFO (or residue fuel oil), typically concentrating sulphur content to HFO that reach shares of 1 % or more. Straight run fuel oil on the other hand typically has a sulphur content under 0.5 %.

As of 2020, the IMO is planning to implement a sulphur cap of 0.5 % for all international waters. Such a regulation would permit only a minor share of global residue fuel oil or HFO to serve as shipping fuel without blending with low sulphur fuel or removal of sulphur through some other measure. Blending HFO with gasoil would make little sense in an advanced refinery where the objective is to separate the two products. A basic refinery, where straight run fuel oil still can be used as shipping fuel, is therefore benefitted compared to an advanced refinery. Refineries with advanced equipment for sulphur removal from VGO could be facing the market for the residue HFO vanishing.

If basic refineries take market shares from advanced refineries, the estimate overall gasoil shares used in chapter 4 would be reduced, which in turn requires an even higher increase in refinery utilization in order to make supply for high value oil products meet demand.

Figure 7

<table>
<thead>
<tr>
<th></th>
<th>Advanced refinery</th>
<th>Basic refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diesel</strong></td>
<td>19%</td>
<td>33%</td>
</tr>
<tr>
<td><strong>Fuel oil</strong></td>
<td>7%</td>
<td>18%</td>
</tr>
<tr>
<td><strong>Gasoline</strong></td>
<td>44%</td>
<td>30%</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>30%</td>
<td>19%</td>
</tr>
</tbody>
</table>

Example production scheme

If basic refineries were to take market shares from advanced refineries and assuming that the refinery slate matches figure 7, the crude oil needed to supply the market with the same amount of diesel would increase by 47 %. Emissions of CO2 would increase at same ratios and it is advised not to implement the 0.5 % sulphur cap without extensive support measures for removal of sulphur from exhaust gases so ships can continue to use HFO.
6. References

CONCAWE 2013. *Oil refining in the EU in 2020 with perspectives to 2030.*

CONCAWE 2014. *Developing a methodology for an EU refining industry CO2 emissions benchmark.*


Elsevier, Transportation Research Part D28 (2014). *Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels.* Brynolf, Fridell, Magnusson and Andersson.


Swedish Forest Industries Federation. Figure published in SWECO report *Consequences of the Sulphur Directive*, 2012.

Swedish Transport Analysis. *Summary Report 2015:11*
trafa.se/en/maritime-transport/implementation-of-the-sulphur-directive--industry-preparations-3353/

TOTAL. Financial Statement for 2015 and 2013 published on [www.total.com](http://www.total.com)