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# Container ship calls: Triple throughput without an increase in marine $CO_2$, $NO_x$ and $PM_{10}$ emissions?

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**Abstract**

A growing world population, economic growth and globalisation of consumption and production have led to a continuous growth of freight transport for decades.
Freight transport is usually motorized, at least in developed countries. It consumes considerable amounts of energy, which lead to considerable emissions of greenhouse gas $CO_2$ and air pollutants like $NO_x$, $SO_2$, $PM_{10}$(and $PM_{2.5}$) both on land and at sea. These emissions constitute a serious threat to planet earth and the health of the species living on it.
Awareness of this problem has led to various steps bygovernments, vehicle suppliers and transport vehicle users to mitigate these emissions.
Containers are a very economical, practical and increasingly popularmeans of transport and storage of goods. Forecasts indicate that the number of TEU's transported worldwide is likely to at least triple in the next 20 years.
Global problems start with local decisions. A local case study is used to answer the question if it is feasible to triple the handling of containers in a specific seaport container terminal by 2033 and maintain its 2008-emission levels of $CO_2$, $NO_x$ and $PM_{10}$ by operational measures at the marine side of this terminal?
This paper indicates that if instruments like fleet renewal, cleaner ship fuels and shore power are combined, a container terminal can triple the number of TEU handled while stabilizing marine $CO_2$ emissions, nearly halving its marine $NO_x$ emissions and drastically reducing its $PM_{10}$ emissions.

*Keywords:*container terminals, operational choices, energy and emission reduction potential.

## 1. Introduction

In this paper two environmental concerns are addressed in relation to container ship manoeuvring and hoteling in a seaport area:

- Climate change (limited to $CO_2$ emissions)
- Air pollution (limited to $NO_x$ and $PM_{10}$. emissions).

In general, $CO_2$ emissions are seen as a global- and $NO_x$, $PM_{10}$ and $SO_2$ emissions as a regional or local environmental problem (along coastlines or in port areas).

### *1.1 Climate change (mitigation).*

The natural greenhouse effect is essential to stabilize the earth's temperature and to allow any form of life. It is a very complex mechanism, not yet fully understood by scientists.

Climate change refers to the rise in global average temperature correlating with emissions of greenhouse gases (GHG) like $CO_2$, $H_2O$, $CH_4$, $N_2O$, $O_3$ and CFCs of natural and human origin. The level of $CO_2$ has become higher than the natural sinks (oceans, forests and troposphere) can absorb. This excess amount of $CO_2$ may correlate with "the observed rapid rise in global mean temperature" (Friis-Christensen et al., 2007, p. 3). The majority of climate researchers mention human activity as the prime cause of global warming (or climate forcing), but some sceptics mention a (persistent) rise in the sun's magnetic activity as the prime cause of global warming (e.g., Friis-Christensen et al., 2007). No one denies the dramatic rise in $CO_2$ emissions of human origin since the first industrial revolution and in particular since the 1950's.

Climate change changes local climates and conditions for food production, with locally positive or negative consequences. It also induces a rise in sea water levels via melting of previously fixed ice formations and increased rainfall.

More delicate is that only a drastic reduction of the human contribution is able to reduce these emissions to a non-harmful level. Climate change mitigation policy has landed on the political agenda in the 1990's. It is "a human intervention to reduce the sources or enhance the sinks of greenhouse gases." It does so by a "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." (IPCC, 2014, p. 4)

### *1.2 Air pollution (abatement).*

Air pollution from burning (fossil) fuels in transport vehicles is on the political agenda for decades. Environmental regulation was introduced to mitigate air pollution. It stimulates behavioural change (e.g. use of more efficient transport means, transport reducing logistic practices) and/or technical innovation (e.g. use of more fuel efficient engines, cleaner fuels and catalytic converters). In Europe, emission standards for surface transport were introduced in stages. Euro I was introduced in 1993-4. Until the year 2000, when Euro III was introduced, freight transport was treated mildly. But then these standards have become much more demanding. The latest Euro 6 standard will lead to a significant reduction in emissions (75% or more below the Euro 1 standards), while manufacturers also have to prove emission reduction over useful life periods (Dieselnet, 2014). Euro standards have a direct impact on the emissions by land vehicles, and via the standards for off-road engine emissions also indirectly on marine engine emissions and on container handling equipment with non-electric engines.

In other countries, in particular the USA, similar emissions abatement schemes are in effect, but in many parts of the world these are still lacking.

*1.3 Towards multilateral action.*

Container transport over sea is a very efficient way of shipping large volumes of goods at reasonable speeds all over the world. It is also a very (price-) competitive way of transport. For example, shipping by air can be 10 times as expensive as sea transport (Container overseas, 2014). These factors and the fact that most of our planet consists of water explain why about 95% of global transport is carried out by sea.

Sea ship emissions of $CO_2$, $NO_x$ and $SO_2$emissions world-wide are aroundrespectively3%, 30% and 10% (Kivi Niria, 2013).

Its global nature, seemingly modest shares in emissions and the fact trade by searepresents a major economicinterest,mayexplainwhy political interest for mitigation of marine emissions has been lacking for decades. Effectively dealing with a complex global issuemeansthatinternationalagreementregarding the direction and nature of multi-lateralaction and an effectiveenforcementmechanismismandatory.

In the pastfewyears, politicalurgencyhasrisento a levelthatallowsinternationalagreementaboutmuch more stringentmulti-lateralaction (European Commission, 2014). The factthatseatransport and in particulartransport of containers isamong the fastestgrowingtransportmodalities (see Figure 1 for Europe) hasprobablybeen the main trigger of thisprocess.

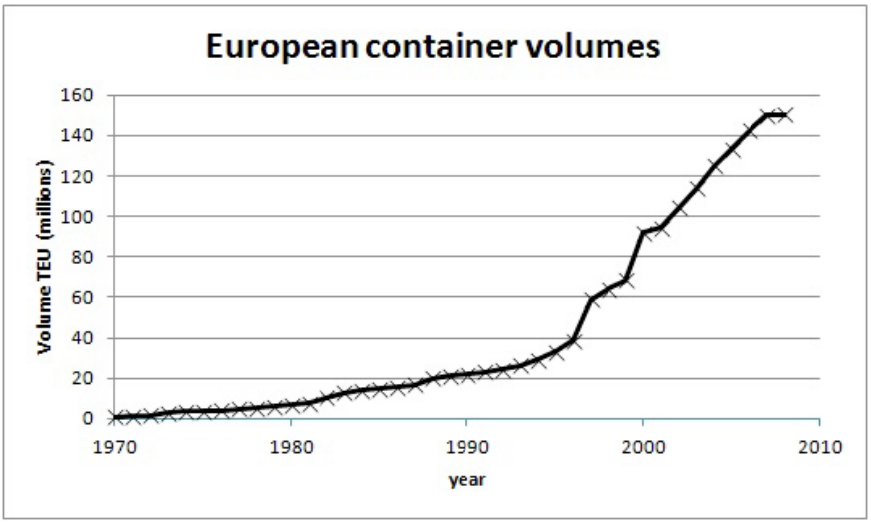


Figure 1: European container volumes since 1970.
Source: Container Statistics (2010).

A growth intransportmeans more fuelconsumption, hencemoreemissions. According to OECD (2011) the volume of TEU transported worldwide could quadruple in the next 20 years. $CO_2$emissions from global shippingcould rise from the present 870 to 2600 mln ton without and to 1600 mln ton with innovative technologies(Kivi Niria, 2013).

In Figures 2 and 3 the development of relevant European emissions by transport(-related) activities since the end of the 1990's can be found. Among the main mitigating factors were the introduction of more energy efficient engines, exhaust cleaning technologies and diesel fuel with a lower sulphur percentage.

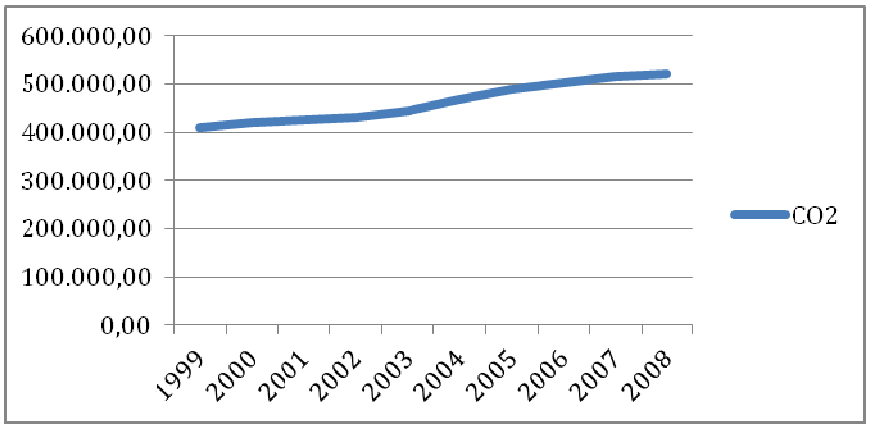


Figure 2: EU-27 1999–2008 $CO_2$ emissions (in metric ktons) by transport, storage and communication industry.
Source: Eurostat (2013).

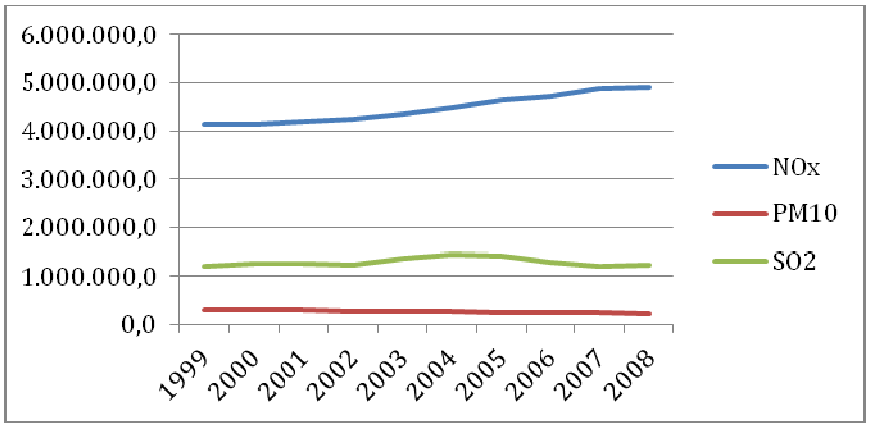


Figure 3: EU-27 1999–2008 $NO_x$, $PM_{10}$ and $SO_2$emissions (in metrictons) by transport, storage and communicationindustry.
Source: Eurostat (2013).

Particulatematter (PM) exists in varioussizes. $PM_{2.5}$-$PM_{10}$ are partially due to mechanicalprocesses, likewear and tear from tyres and industrial processes and partially due to re-suspension of particles from the ground and roadsurfaces by wind or humandactivities. $PM_{2.5}$ismostly due to combustion of fuels in engines and regardedasveryunhealthy, becausetheir small sizeallowsdeeppenetrationinto the lungs. Particles are emitteddirectly or - especially in summer – indirectlygenerated by a processcalled gas-particulateconversion. In thisprocess, $SO_2$ and $NO_x$emissions from shipstravelling in North and East Sea watersmovehundreds of kilometresinlandwheretheymeet with $NH_3$emissions from agriculture. Thisleads to veryunhealthyconcentrations of $SO_4$ and $NO_3$ (aerosol clouds) (Corbett, 2007; Krause et al., 2006; Matthias et al., 2010; Matthias, 2014).

Due to lack of local data, particlessmallerthan $PM_{10}$ and of $SO_2$wereexcluded. For practicalreasons, otherenvironmentalimpacts, suchaspollution of the soil or water werealsoexcluded.

In Europe 49.500 deathswereattributed to shipemissionsalone in the year 2000. Itispredictedthatthisnumberwill rise to 53.200 in 2020, despite more stringentenvironmentalregulation (Brandt et al., 2011).

The global economiccrisis (2008-2013) hasdampenedgrowth of container transport. Economicgrowthhasalreadyreturned in major world markets, hence container transportislikelyto continue itsformergrowthpath.

### *1.4 The research question.*

It is assumed that container transport will grow exponentially in the next 20 years. Taking into account structural issues in the world economy and various other uncertainties, it may be better to replace the mentioned quadrupling in volume by a tripling. Assuming a bottom-up approach, local intervention could then help finding an answer to the following research question:

*Is it feasible to triple the handling of containers in a specific container terminal and maintain its 2008-emission levels of $CO_2$, $NO_x$ and $PM_{10}$ by operational measures at the marine side of the terminal?*

This is a well-developed research area, both by consultants (Sisson et al., 2012) and scientists (Kontovas et al., 2010; Wilde et al., 2008). This paper adds a local case study It is a follow-up on a recent paper (Vleugel et al., 2014) and part of on-going research into the environmental aspects of (containerized) freight transportation.

### *1.5 Set-up of the paper.*

Section 2 extends the initial problem analysis of section 1. Section 3 explains the methodology used. In section 4 scenarios are used to estimate the potentially achievable emission reductions by the selected operational options. An evaluation can be found in section 5. Conclusions and recommendations are presented in section 6.

## 2. The system and the problem

The analysis of a seaport container terminal starts here. First, an introduction is given into environmental management of a container terminal (section 2.1). Next, the terminal will be described in more detail (section 2.2). Government policy is discussed next (section 2.3). Section 2.4 contains a summary.

### *2.1 Container terminals and environmental management.*

The marine emissions at a container terminal are mainly determined by decisions of four groups of actors: container terminal owners, shipping lines, manufacturers of terminal equipment and (local) governments. They may initiate many actions to reduce emissions to the air (APEC, 2009):

1. Modal shift

2. Reduction of traffic congestion
3. Hybrid or electrical cargo-handling machines (terminal equipment)
4. Shore-to-ship power supply (‘cold-ironing’) for mooring ships
5. Cleaner or renewable sources of energy
6. Green space and carbon offset
7. Carbon capture and storage (CCS)
8. Planning and quantification.

Actions 4 and 5 are in the scope of this paper.

Seaport container terminals are frequently near or in densely urbanized areas, compromisingthe life of many people (AirClim et al., 2011). This explains why governments in many countries stimulate terminal operators to reduce air pollution. An example is the US’ Environmental Protection Agency (EPA), who uses specific regulatory and financial instruments for seaport container terminals (EPA, 2014).

Shipping lines, the main customer of container terminals, may also take action by ‘greening’ their supply chain, demanding their partners to add their fair share. Parties may join forces at the operational level, for instance by using optimized ship stowage plans for a particular port (Ilmer, 2006). This allows optimized discharge and load cycles of quay cranes (single or dual cycling), which reduces turnaround time of ships, optimizes use of container handling equipment (Zhang et al., 2009) and reduces energy consumption and emissions to the air.

A recent study (Merk, 2012) shows that there is a complex relation between emissions, number of calls and turnaround time. More calls per seaport lead to more emissions, hence the busiest ports in the world also have the most air pollution. Eurasian sea trade is the most developed; hence ports in Europe and Asia have the most air pollution. The busier a port, the more it pays to reduce turnaround times. This reduces emissions per turnaround. Ship sizes are also important. In Europe, frequent use is made of short sea shipping, which leads to more ship calls per port. However, no correlation between ship volume and emission volume could be found in Rotterdam (Merk, 2012). In Africa and Oceania, ship calls usually take much more time than in other parts of the world, which explains why in those areas pollution per call is much higher than the (world) average.

Manufacturers of terminal equipment have an interest in selling the most productive equipment with the lowest energy consumption and emissions. A major development in container terminals since the 1980’s is automation of planning and yard processes (PEMA, 2012; Scott, 2012). Automated vehicles allow higher spatial densities (hence shorter driving distances) and more controlled driving, both of which reduce fuel consumption (Sisson, 2006). Electrification is the next major development, both on land (electric or hybrid diesel-electric engines replacement diesel engines in container handling equipment) and for ships (electric connection instead of a running ship diesel engine). This reduces local air pollution significantly (ABB, 2010). When emissions on the landside of a terminal are reduced significantly, attention (of policy makers) increasingly goes to the marine side of a terminal.

Manufacturers of ships, owners of shipping lines and the Marine Environment ProtectionCommittee (MEPC) of the International Maritime Organisation (IMO) are in a comprehensive process; greening of sea shipping. The International Convention for the Prevention of Pollutionformships (MARPOL) isregularlyadaptingitsregulation. IMO

currentlymandatescleaner marine technologies, for instance, enginesrunning on lowsulphur diesel (IMO, 2014). Technical developments, like the ongoing growth in ship sizes, the introduction of slow steaming, the introduction of LNG to replace diesel in the ship engines and on-shore electric power supply for berthing ships (Green4Sea, 2014; BSR, 2010) are signs that the key players in the industry are developing options which allow matching of economic and environmental concerns.

### *2.2 A container terminal at Rotterdam's Maasvlakte 1.*

The Maasvlakte 1 port area has contributed in a major way to the worldwide boom (7 fold growth) in container transport since the 1980's, because ECT (owned by Hutchinson Port Holdings Limited (HPH) was the world's pioneer in automation of container terminals.

A case study of ECT's Delta container terminal in the Maasvlakte 1 area will be used as data provider. It is located at the corner of the Europa port and the-Amazone port. It has a total area of 265 ha., a quay length of 3.6 km. and allows sea ships with a maximum depth of 16.65 m. Its 36 quay cranes allow handling of sea ships with a maximum span of 22 containers wide (ECT, 2014).

Container handling capacity is determined by whole range of factors, both technical and non-technical, an elaboration of which could easily take a few other papers. In (reference year) 2008, 3.08 mln.containers were handled (Geerlings et al., 2012).

### *2.3 Local government policies.*

The Netherlands isamong the largestim- and (re)exporters of goods in the world. Rotterdam is the leadingEuropeanhub for goods from all over the world, in particular Asia. High growthscenarios for container transport, growth in vessel sizes and lack of space in the olderportareas, in particularMaasvlakte 1, led the Port of Rotterdam Authority to develop the Maasvlakte 2 area, largelyfunded by the nationalgovernment. The first phase of this area (700 ha. intotal) istechnically ready and partiallyused for container handling. When the secondphasebecomesoperational in 2035, the present 11.62 mln. containers per yearhandled by all container terminals in Rotterdam, includingECT's Delta terminal, could be enhanced by an additional 17 mln. (World Shipping Council, 2014)according to the pre-2008 growthscenarios. The fuzzyness of economicforecastscombined with portexpansion in othermainEuropeanportsmakepredictionsabout future volumesratheruncertain. Ifdemandstaysbehind, thereis a risk of overcapacity.

The Rotterdam-Rijnmondregionalreadyhas the poorest air quality in the Netherlands. European air qualitystandardscannot be kept. Furtherexpansion of portactivitieswillworsenthisproblem. Poorer air qualitymayalsohave negative economicconsequences in terms of reducedattractiveness of the city to citizens and companies and lowereconomicgrowth.Hencethe Rotterdam ClimateInitiative to reduce theregional$CO_2$emissions in 2025 by 50% ofthose in 1990 (City of Rotterdam, 2013). Air quality targets weredevelopedbeforeMaasvlakte 2 engineeringworksstarted. Local emissions of PM, $NO_x$ and $SO_2$ in 2020 should be atleast10% lowerthan in 2010. A drasticreduction of the growth in truck transportshould be realised due to a major modalshift in favour of barge and rail (Port of Rotterdam, 2011).

## 3. Methodological framework and choices

The research will explore options to stabilize the of $CO_2$, $NO_x$ and $PM_{10}$ emissions by mooring ships at the 2008 levels, while the throughput of ECT's Delta terminal triples around 2033. Other environmental impacts are not in the scope of the paper.

### *3.1 Research activities.*

This paper is based on a desk research into emission parameters, developments in container handling equipment, ship technology and electricity production. Discussions with terminal operators learned that they, because of competitive reasons, are usually unwilling to share data with outsiders that might have (remotely) commercial value, in particular operational strategies and detailed performance. To avoid discussions about the use ofconfidential data, only publicly available data was used.

Several emissions abatement scenarios were developed. The future environmental situation was defined as 'zero growth' in $CO_2$ emissions only, leaving degrees of freedom for the other emissions parameters. Back casting scenarios were a logical choice. The conditions defined in the scenarios were then fed into an input-output simulation model that was developed in MS Excel©. The model allows simulation of the relevant future emission stabilization alternatives.

### *3.2 Assumption: Handling capacity is not a bottleneck.*

In the simulation we assume that the yearly container throughputof the ECT terminal in 2033 is much higher than in 2008. Call sizes and quay crane productivity are already increasing. The latest discharge and load record was 11.051 containers during one ship visit of a Thalassa class vessel of the Evergreen Line (ND, 2015). By combining larger vessels with an increase in the number of vessels and the latest cranes, millions of additional containers can be handled, provided that the landside productivity and the hinterland transport capacity are adapted correspondingly. The landside capacityis out of scope and will therefore be considered as infinite.

Figure 4 is a generic picture of a seaport container terminal. In this paper only the top section is relevant.

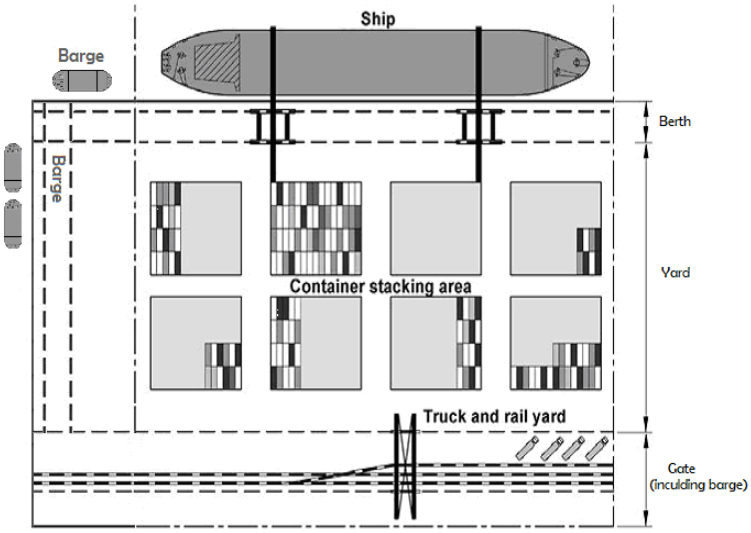


Figure 4: Examplelayout of a seaport container terminal.
Source: Brinkmann, 2011.

## 4. The scenarios

Scenarios will be used to explore the potential to abate $CO_2$. $NO_x$ and $PM_{10}$ emissions. They contain:1. Current and alternative fuels in 2008 (in section 4.1), resp. 2033 (in section 4.2); 2.Increasing ship sizes (in section 4.3); 3.A combination of alternative fuels and shore power (in section 4.4).

### *4.1 Scenarios for fuels in 2008.*

During a port call a sea container ship uses its main engine to enter the basin in the port adjacent to the container terminal and progresses to the destined quay location where it will stay for discharge and loading, also known as hoteling. To reduce complexity, the use of tow boats or on-shore mooring systems is not in the scope. Before entering the port and during its stay in the port, diesel fuelled generators are powered up and continue to run in order to supply electricity to basic support systems and temperature controlled cargo (in reefer containers). A hoteling container ship may use between 1 and 7 Megawatts per call (Doves, 2006).

The marine side contributes to the emissions of handling containers. In 2006 8% of the ambient $PM_{10}$ and 19% of the $NO_x$ emissions in the Rotterdam port area were by shipping, most of which while sailing (Doves, 2006). These absolute percentages are for all ships visiting the port, no details for container ships were available.

#### *4.1.1 2008 Reference scenario: Single fuel (HFO).*

Fuel cost is the main operational cost of shipping. A container ship sailing at an optimal cruising speed of 24 knots per hour consumes 225 ton HFO (heavy fuel oil). Options, such as sailing at lower speeds reduce fuel consumption drastically, but increase sailing time as well.

HFO is the cheapest fuel. It is an asphalt-like substance, which unfortunately has the highest emission parameters of all marine fuels.When HFO is used during manoeuvring and hoteling, the input-output model generates the following estimates of emissions to the air for ECT's Delta terminal (Table 1).

Table 1:2008 emission estimates from ships using HFO for manoeuvring and hoteling when 3.08 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 16802 | 342 | 35 |

Source: Own calculations.

*4.1.2 2008 Alternative scenario: Bi-fuel (HFO + MDO).*

An interesting option to reduce emissions by sea shipping is to use MDO (marine distillate oil) forhoteling. MDO is one of the alternatives for HFO in marine applications. As Table 2 shows, the use of MDO reduces $PM_{10}$ emissions substantially. In contrast, only small reductions in emissions of $CO_2$ and $NO_x$ can be achieved. This is due to the fact that (most) current engines are optimized for HFO and cruise speeds at open sea. HFO and MDO are chemically and energetically different products, which has important consequences for fuel combustion. Ship engines are not used in a very economical wayin ports. Use of MDO also leads to major changes in the way ship engines are operated and technical adaptations to pumps and other subsystems. In conventional marine engines, switching from HFO to MDO may easily lead to power loss or even a complete blackout. The advice to operators is to carry out this complex operation not at sea, but at the berth (Blog Fair de maritime, 2013).

MDO is already common in feeder ships in Europe in order to comply with environmental regulation in the North- and East Sea basins. Since 2007 so-called SulphurEmission Control Areas (SECA's) becameactive. The aimwasto reduce $SO_2$emissions from shipping by reducing the amount of sulphur in marine diesel fuel from 4.5% (non-SECA, rest of the world) to 1.5% max. Thereis catch, asdesulphationwilllead to a substantialincrease in $CO_2$emissions from refinery (VNPI, 2006). SECA was (therefor) notmeantto reduce $CO_2$ or$NO_x$ emissions (Brandt, 2011). MDO is not a waste product, but a refinery product. Its production cost is higher than HFO. The higher margin on MDO may induce a switch from HFO to low sulphur MDO, which makes investments in refinery (estimated at US$ 120 bln. worldwide) worthwhile (An. editor, 2015). If SECA areas would be extended to other parts of the world then major shipping lines will have to (completely) switch to alternatives like MDO. A cheaper alternative, also lowering PM emissions, may be on board washing of exhaust gases (also called scrubbing). This costs energy and large amounts of seawater, however (Blog Fair de maritime, 2013). The use of other fuels, in particular LNG, is not in the scope of this paper.

Table 2:2008 emission estimates from ships using HFO for manoeuvring and MDO for hoteling when 3.08 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 16254 | 328 | 14 |

Source: Own calculations.

*4.2 Scenarios for fuels in 2033.*

*4.2.1 2033 Base scenario: Single fuel (HFO).*

Tripling the number of TEU can (theoretically) be achieved by an increase in port calls with the same ship sizes. Table 3 presents estimates for the three types of emissions in 2033. All emissions rise linearly compared with Table 1.

Table 3:2033 emission estimates from ships using HFO for manoeuvring and hoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 50405 | 1026 | 105 |

Source: Own calculations.

*4.2.2 2033 Alternative scenario: Bi-fuel (HFO + MDO).*

A variant with the same volume, but with ships using MDO instead of HFO leads to the values in Table 4. Comparing Table 3 with Table 4, it is clear that a small reduction in $CO_2$ and $NO_x$ and a major reduction $PM_{10}$ emissions can be achieved by using MDO for hoteling.

Table 4:2033 emission estimates from ships using HFO for manoeuvring and MDO for hoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 48761 | 985 | 41 |

Source: Own calculations.

*4.3Alternative scenarios for fuel and fleet replacement in 2033.*

*4.3.1 2033 Single fuel (HFO) + fleet replacement (larger container ships).*

Increasing economies of scale and the ability of engineers to lift technical boundaries have led to the large vessels we see today. This has induced port authorities and terminal operators to offer port facilities that allow these ships to be handled.

Fleet replacement and transfer of smaller ships to routes with ports with smaller call sizes is a natural element of this process. With an average operational life of about 20 years many ships currently visiting Rotterdam port will be used on other motorways of the sea before 2033. Here it is assumed that 50 per cent of the ships visiting the ECT Delta terminal in 2033 will be in the Suez- and 50 per cent in the Post-Suez class. It is

assumed that a (post-)Suez class ship uses the same amount of fuel as a (Post)Panamax class ship it replaces, but carries more TEU. Hence itsfuel respectively emission to weight ratio is reduced. For feeder ships we assume no change in ship sizes. This leads to the estimates of Table 5.

Table 5:2033 emission estimates from ships using HFO for manoeuvring and hoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 40165 | 818 | 83 |

Source: Own calculations.

*4.3.2. 2033 Bi-fuel (HFO + MDO) + fleet replacement.*

Use of MDO forhoteling leads to (slightly) lower emissions for future ships. The emissions produced will be 2.39 times those of the 2008 benchmark. So, using larger container ships reduces the steep upward trend in emissions by ship maneuvering and hoteling, but it does not lead to the required zero growth in emissions.

Table 6:2033 emission estimates from ships using HFO for manoeuvring and MDO forhoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 38794 | 783 | 30 |

Source: Own calculations.

*4.4 Alternative scenarios for fuelin 2033.*

*4.4.1 2033 Single fuel (MDO) + shore power.*

Legislation may lead to a complete replacement of HFO by MDO and use of shore power for hoteling (Table 7).

Table 7:2033 emission estimates from ships using MDO for manoeuvring when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 8826 | 178 | 3 |

Source: Own calculations.

With shore power the emissions from maneuvering become much lower.Hoteling becomes a much cleaner process. The following estimates are found (Table 8) assuming (conservatively) the Dutch energy mix for shore power of 2008 (Hulskotte et al., 2008).

Table 8:2033 emission estimates from ships using shore power from the grid during hoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 25917 | 22 | 0,4 |

Source: Own calculations.

Combining all measures, the following estimates are generated (Table 9).

Table 9:2033 emission estimates from ships usingMDO for manoeuvring and shore power from the grid during hoteling when 9.24 MTEU are transferred annually.

| | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| In ton p/yr | 34743 | 200 | 3,6 |

Source: Own calculations.

## 5. Evaluation and extension

It is feasible to triple the amount of TEU processed by this terminal with an almost doubling of $CO_2$ emissions, and a major reduction in the emissions of $NO_x$and $PM_{10}$ if all visiting container use shore power from the Dutch grid (calculated with the 2008 emission parameters).

This is of course notthe aim of this back casting study. The following, additional, analysis step was needed. A larger market share of wind, solar and hydropower, and technical innovations in the (imported) electricity production will very likely lead to a reduction of the emission factors for electricity by 2033.A forecast for the Dutch energy mix in 2030(Gijsen, 2001) mentions a reduction in $CO_2$ emissions from 285 g/kWh to 192 g/kWh. $NO_x$-emissions are likely to drop from around 0.5 g/kWh to 0.192 g/kWh in 2030. A forecast forfuture $PM_{10}$ emissions was not available, but they are likely to drop as well. Gijsen (2001)used two alternative methods to calculate emission factors: the integral method and the SSS method (highest reduction in emissions).

Translated to the ECT Delta terminal, this results in the estimates of Table 10.

Table 10:2033 emission estimates from future ships using MDO for manoeuvring and shore power based on an energy mix estimated by the SSS method when 9.24 MTEU are transferred annually.

| In ton p/yr | $CO_2$emissions | $NO_X$emissions | $PM_{10}$emissions |
|---|---|---|---|
| 2008 | 16802 | 342 | 35 |
| 2008 x 3 | 50405 | 1026 | 105 |
| 2033 min (SSS scenario) | 17051 | 186 | - |
| Change | 1,5 % | -45,6 % | - |

Source: Own calculations.

Now the $CO_2$-emission level in 2033 is almost equal to the onein 2008.

In order to facilitate these changes, substantial investments are necessary. Fleet renewal is an on-going process, driven by technical, economic and environmental considerations.

The choice between MDO and shore power is a complex one, in which the difference in fuel cost and investments in electricity supply on the ship and on land are incorporated. Cost of a port call of one day equal US$ 4.200 for 1.6 MW (with shore power) or US$ 9.000 for MDO (Sisson et al., 2010). Investment cost vary dependent on the local conditions. The high cost of MDO is partially due to lack of refining capacity. Mandatory use of MDO may induce mass production of this fuel, which will lower its cost. A (temporarily) higher cost of sea shipping is not a bad thing. It is compatible with the polluter pays principle. It is also defendable, as it induces technical innovation and changes in logistic strategies.

Switching to MDO is probably not the most cost-effective-, but rather an intermediate step. Major manufacturers of marine engines are already exploring multi-fuel engines, which allow use of up to three different fuels to accommodate various situations (Germanischer Lloyd et al, 2011; Karanc, 2011).

## 6. Conclusions and recommendations

This study of the marine energy use and emissions at a sea port container terminal indicates that it is technically feasible to triple the TEU-volume at this container terminal while stabilizing the $CO_2$ and cutting the $NO_x$-emissions and $PM_{10}$ emissions drastically. This can be realized with an interesting blend of (policy) instruments: fleet renewal, cleaner ship fuel (single or multi-fuel) and obligatory use of shore power from a much cleaner mix of sources. Such a blendfits nicely with the polluter pays principle.

Technical innovation is a continuous process. Next to the options contained in the scenarios, a wider range of options can be explored using the model applied in this paper.

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