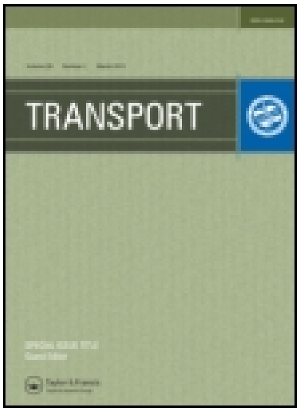

Transport
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tran20

Maritime traffic externalities in the Gulf of Finland until 2030

Juha Kalli [a] , Reetta Saikku [a] , Sari Repka [a] & Ulla Tapaninen [b]

[a] Centre for Maritime Studies, Environmental Research and Regional Development , University of Turku , P.O. Box 181, FI-28101 , Pori , Finland

[b] Centre for Maritime Studies, Maritime Logistics Research , University of Turku , Heikinkatu 7, FI-48100 , Kotka , Finland

Published online: 30 Mar 2012.

TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2012 Volume 27(1): 92–101
doi:10.3846/16484142.2012.668497

MARITIME TRAFFIC EXTERNALITIES IN THE GULF OF FINLAND UNTIL 2030

Juha Kalli[1], Reetta Saikku[2], Sari Repka[3], Ulla Tapaninen[4]

[1, 2, 3]Centre for Maritime Studies, Environmental Research and Regional Development, University of Turku, P.O. Box 181, FI–28101 Pori, Finland
[4]Centre for Maritime Studies, Maritime Logistics Research, University of Turku, Heikinkatu 7, FI–48100 Kotka, Finland
E-mails: [1]juha.kalli@utu.fi; [2]reetta_saikku@yahoo.com; [3]sari.repka@utu.fi; [4]ulla.tapaninen@utu.fi (corresponding author)

Submitted 7 March 2011; accepted 4 April 2011

Abstract. Maritime traffic in the Gulf of Finland has grown remarkably during the 2000s. This increase has an impact on the environment and exposes it to risks. These problems should be controlled to guarantee sustainable development and the welfare of inhabitants in the area. A method for estimating the impact of ship-originated air emissions on the environment is to calculate their environmental externalities which are a part of the total marginal social costs of shipping. The internalization of externalities as a control method of transport would comply with the polluter pays principle and act as a fair traffic control method between transport modes. In this paper, we present the results of CO_2, NO_x, SO_x and PM emissions originating from ships and their externalities in the Gulf of Finland up to 2015. The calculation algorithm developed for this study produces emission estimates per annum and converts them into externalities. We focus on passenger, tanker, general cargo, Ro-Ro, container and bulk vessel ship types representing almost 90% of the total NO_x emissions of shipping in the area. Scenario modelling is a method for estimating the effects of forthcoming or planned regulations and helps with targeting emission abatement actions to maximize their profit. The results of the calculation algorithm show that externalities can be used as a consultative tool for transport-related decision-making. The costs are given at the price levels of the year 2000. The total external cost of ship-originated CO_2, NO_x, SO_x and PM emissions in the Gulf of Finland was almost €175 million in 2007. Due to increased traffic volumes, these costs will increase to nearly €214 million in 2015. The majority of externalities are produced by CO_2 emissions. If we deduct CO_2 externalities from the results, we get total externalities of €57 million in 2007. Following eight years (2015), externalities would be 28% or €41 million lower. This would be as a result of regulation reducing the sulphur content of marine fuels. Regulating SO_x and PM emissions will slow down the increasing trend of shipborne externalities in the Gulf of Finland; however, the externalities are still growing. In order to achieve a downward trend, the two major compounds resulting in externalities must be reduced, which requires strict actions to lower shipborne CO_2 and NO_x emissions.

Keywords: Gulf of Finland, Baltic, shipping, atmospheric emissions, health effect, cost, externalities.

1. Introduction

Maritime traffic makes up a large fraction of anthropogenic air pollution in the Gulf of Finland and the Baltic Sea. This region has experienced a large increase in traffic since the 2000s, which is expected to continue (Lloyd's Register 2009; Klemola *et al.* 2009). The transportation of oil products from the Russian ports of the Gulf of Finland has significantly increased and is expected to continue in the future. The emissions of exhaust gases and particles from seagoing ships impact the chemical composition of the atmosphere, local and regional air quality and climate. The emitted key compounds include carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), hydrocarbons (HC) and particulate matter (PM) (Lloyd's Register 1995). The severe eutrophication of the Gulf of Finland and the Baltic is the main environmental concern for the region. The contribution of shipping can represent up to 50% of the total N input in some areas and seasons, and can therefore significantly add to the eutrophication of the Baltic (Stipa *et al.* 2007). Under business-as-usual assumptions, by 2020, emissions from maritime activities will have come close to the projected baseline emission levels from land-based sources and surpass the target levels established by the European Commission in its Thematic Strategy on Air Pollution for land-based sources (Cofala *et al.* 2007).

Studies have shown that the primary reason for the large impact of shipping emissions on health is due to the fact that 70% of shipping occurs within 400 km of land and the major shipping ports are located in areas surrounding large populations (Corbett *et al.* 1999; Corbett, Koehler 2003; Endresen *et al.* 2003; Eyring *et al.* 2005; Derwent *et al.* 2005; Wahlström *et al.* 2006). The results by Corbett *et al.* (2007) estimate that shipping-related PM emissions from marine shipping contribute approximately 60000 deaths annually on a global scale with impacts concentrated in coastal regions on the major trade routes.

Action is finally being taken through policies and regulations to deal with environmental and health impacts caused by the maritime industry. As a result, the industry is facing large changes in the near future brought on by upcoming regulations. The key issue that is still not completely clear is how well these regulations will clean up the emissions of maritime traffic and what the final costs of these procedures will be.

The Gulf of Finland (Fig. 1) makes up the most eastern part of the Baltic Sea and is bordered by Finland, Estonia and Russia. The Gulf, as well as the whole of the Baltic, is a shallow marine area with a narrow connection to the North Sea and Atlantic making the ecosystem very vulnerable to any disturbing factors. This, together with the fact that maritime traffic in the already busy Baltic is only expected to keep increasing, makes the Gulf of Finland a key region and an important topic of study.

Traditionally, any detrimental effect on human health, the environment or buildings by maritime traffic has not been included in the market price of transport, i.e. they were largely external costs. By transferring these effects into externalities and actual monetary units, we can convert environmental and health impacts into an easily applicable and understood form.

The objective of this paper is to estimate how emissions and their costs will vary in the future. This study provides estimates of the effects of the forthcoming and planned regulations as well as a comparison of abatement actions to maximize their profit. The structure of the paper is as follows: Chapter 2 presents the methodology of the study and discusses how the atmospheric emissions of vessels are calculated; followed by the emission externalities calculations based on traffic growth and ship renewals in the Baltic Sea in the future. Chapter 3 discusses the results of the calculations. The special cases of nitrogen oxides, sulphur oxides, carbon dioxides and particles are discussed separately. Chapter 4 presents the conclusions.

2. Methodology

In its simplest terms, the scenarios of future externalities require calculating atmospheric emissions from different pollutant compounds (described in detail in Section 2.1) which are then multiplied by the pre-determined cost per ton of compound and extrapolated into the future. We have used the cost per compound as calculated by the Ministry of Transport and Communications of Finland (MINTC 2003) using the bottom-up methodology considered the most accurate method for the study due to reasons set out in Sections 2.2 and 2.3.

2.1. Calculating Emissions

Atmospheric emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), particles (PM), sulphur dioxides (SO_2) and carbon dioxide (CO_2) from shipping are calculated for vessels calling to Finnish ports in the Gulf of Finland (Table 1). The emissions are estimated for a voyage to and from a port in the shipping channels. They are also based on port calls for each category of vessels as well as the voyage distance and the average speed of a ship per one port call. Using the average lay time at port for a vessel, emissions in the port area can be estimated. Manoeuvring time in the port area is not included in the calculations. The distance between each port and the exit point, through which it is presumed all vessels sail when travelling abroad, is determined (Fig. 1). Every vessel travels from that point to a port and back per one port call.

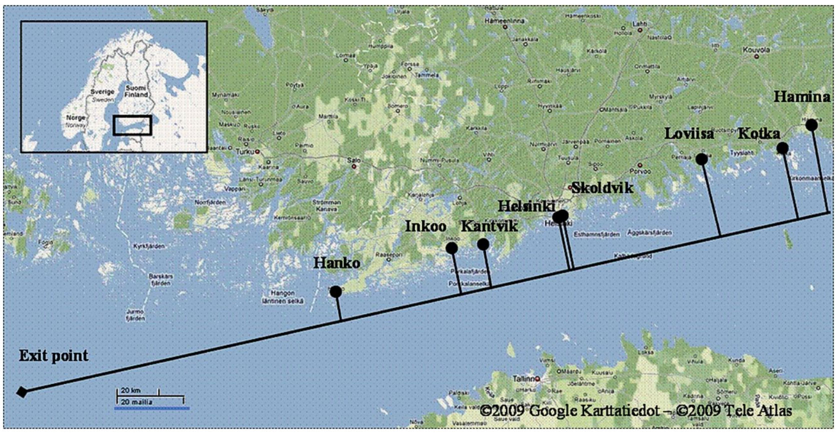

Fig. 1. A map of the Gulf of Finland showing locations of ports included in the study – the estimated route from the harbour through the near coast (first 22.2 km) section and to the open sea Gulf of Finland exit point is also shown

Table 1. A list of ports included in the study with a distance from each port to the Gulf of Finland exit point (see Fig. 1) and the share of the near coast (defined as the first 22.2 km of the journey from the harbour) and open sea (the area outside the initial 22.2 km) in the total voyage emissions

Port	Port calls in 2007	Voyage distance via shipping channel (one way) [km]	Share of near coast emissions in the total voyage emissions [%]	Share of open sea emissions in total voyage emissions [%]
Hamina	1587	460	5	95
Hanko	1457	210	11	89
Helsinki	10881	310	7	93
Inkoo	529	270	8	92
Kantvik	215	280	8	92
Kotka	2842	420	5	95
Loviisa	350	400	6	94
Sköldvik	1048	360	6	94

Simplifying the route to a straight line may introduce some uncertainty into the calculations, however, the small study area of the Gulf of Finland, helps to minimize this uncertainty.

Data for the calculations come from port traffic service information received from the Finnish Maritime Administration for the full calendar year of 2007. Ships are divided into cargo and passenger vessels and a further division is made by gross registered tons (GRT) that fall into seven weight categories (300–999, 1000–2499, 2500–4499, 4500–7999, 8000–11999, 12000–20999, >21000 GRT). The calculation of emissions is based on data on port calls and variables in the inventory system of MEERI emission listed per compound (Mäkelä *et al.* 2008). Detailed information such as averaged installed power, main and auxiliary engine load (see Table in the Appendix for full data). The values are applicable for all ships visiting Finnish ports. Cargo and passenger vessels are considered separately due to differences in ship attributes and operational variables. Cargo vessels have both four and two stroke engines as the main engines. The share of two and four stroke engines is taken into account separately for each ship category. Passenger vessels are assumed to have only four stroke engines. All auxiliary engines are assumed to be four stroke engines. The load percentage of the main and auxiliary engines varies depending on the operation mode. Two different operational modes are used in this study: open sea and in port. The main engines are assumed to be shut down when at port.

Fuel consumption, SO_2 and PM emissions are calculated separately for the main and auxiliary engines, thus allowing the consideration of the effect of changing ship fuel quality according to international regulations. It is assumed that all port calls, regardless of ship type, comply with the 0.1% EU limit after 1 January 2010. All ships in the future scenario calculations are assumed to comply with the 2010 and 2015 SECA limits. The average sulphur content of cargo and passenger ships is different based on the MEERI system (Mäkelä *et al.* 2008), which is taken into account when reducing SO_2 and PM emissions in the future scenarios. SO_2 emissions are assumed to decrease linearly with the same rate as the sulphur content of ship fuel. PM emissions (g/kWh) are assumed to decrease by 0.5778 times and fuel sulphur content with an offset of 0.2967.

Fuel consumption is estimated for ships by dividing it between voyage and in port consumption. The main and auxiliary engines are also considered separately; the main engines are used at sea and burn heavy fuel while the auxiliary ones are used mainly at port and burn marine gas oil. This allows the calculation of fuel costs by estimating the amount of heavy fuel oil (LS380) and marine gas oil (MGO) consumptions. Fuel prices on 20 November 2009 were €319 and €430 for LS380 and MGO respectively (Bunkerworld 2009). The share of LS380 in the EU ports is assumed to have been 95% until 1 January 2010 and to have switched completely to MGO due to the 0.1%–S directive following that date. During the voyage, the share of LS380 will be 95% until 2015. Therefore, the share of used MGO will be 5% during the voyage until 2015. It is assumed that all fuel consumption will be MGO in port and during the voyage after 1 January 2015. The emissions are calculated separately for all emission compounds, operation modes, ship categories and harbours. MGO is the only ship fuel complying with a 0.1% sulphur limit today.

2.2. Calculating Emission Externalities

Externalities are calculated by multiplying emission tons with the cost of a corresponding unit for a specific compound (Table 2) and are presented as € per ton of pollutant. The cost per compound for Finland is based on calculations by the Ministry of Transport and Communications of Finland (MINTC 2003) using a modified *ExternE*-project method (European Commission 2004; Mäkelä *et al.* 2008). Each pollutant (except for GHGs) has its own statistical exposure-response function, certain concentration of emission which causes a specific detrimental effect on the population, buildings and/or nature. Unit costs have been calculated for health effects (lung and heart disease, cancer, acute and chronic years of life lost), its impact on building materials (damage to stone/metal/paint surfaces) and terrestrial ecosystems

Table 2. Emission externalities for the open sea, near coast and harbour spatial divisions – unit costs are given per compound and spatial category (€/t) (MINTC 2003)

Compound	Open sea (Baltic Sea) [€/t]	Coast [€/t]	Harbour [€/t]
CO	0.4	2	19
HC	137	153	148
NO_x	301	397	1062
PM	3410	5610	26880
CO_2 Scenario 1	32	32	32
CO_2 Scenario 2	19	19	19
CO_2 Scenario 3	9	9	9
SO_2	327	547	2283

(crop loss) reflecting an economic impact of the damage caused. The costs specified for Finland and which are used here as the emission externalities are based on the European average figures calculated by Friedrich and Bickel (European Commission 1997, 2004) and a specific Finnish study (Otterström *et al.* 1998).

The spatial distribution of emissions is divided between the harbour, coast (here defined as the 12 nautical mile, or approx. a 22.2 km zone of territorial waters) and open sea beyond that. The percentage share of 22.2 km from a port to the focus point is calculated and used for dividing the total voyage emission into these two spatial categories. Therefore, for any ship taking a more coastal route, this would result in the underestimation of the distance spent within the (higher cost) coastal region and therefore in the underestimation of the total externality. Exposure has been calculated for population and terrestrial ecosystems quantified based on Finnish population and other statistics data. The exposure of building materials is based on a Swedish study by Friedrich and Bickel (European Commission 1997, 2004) modified to the Finnish population.

CO_2 is a greenhouse gas and is thus not bound to the location of its emission and consequently does not affect the unit cost. Greenhouse gas externalities have traditionally been calculated according to the global climate change impact it would cause. However, this figure is conservative in the sense that only damage that can be estimated with a reasonable certainty is included; for instance, impacts such as extended floods and more frequent hurricanes with higher energy density are not taken into account as there is not enough information about the possible relationship between global warming and these impacts. The current value published by the Ministry of Transport and Communications of Finland (MINTC 2003) is €32/t CO_2 – the average value of *ExternE* calculations from 1997, €18–46/t CO_2, (European Commission 1997). MINTC has for the time being decided to use this average of the *ExternE* range in order to provide policy making a stable estimate to work with, even though lower values are possible. The new *ExternE* average estimate (European Commission 2004) is €19/t CO_2 (this estimate is in line with reaching Kyoto targets, with the price of tradable CO_2 permits and with CAFÉ estimates). The lower bound is determined by the damage cost approach to about €9/t CO_2. For this study, we have therefore calculated three alternative CO_2 scenarios with t CO_2 costs of €32, €19 and €9.

On 10 October 2008, the Marine Environment Protection Committee of the International Maritime Organisation, IMO, unanimously adopted the revised Annex VI, the Prevention of Air Pollution from Ships, to the MARPOL 73/78 Convention. The Annex sets limits on nitrogen oxide and sulphur oxide emissions from ship exhausts.

NO_x emissions from new ships are based on 3 Tier standards (Tier I, Tier II and Tier III) defining emission levels for marine diesel engines installed on ships after a certain construction year. Tier I applies to the marine diesel engine installed on ships constructed on or after 1 January 2000 and prior to 1 January 2011. Tier II applies to the marine diesel engine installed on ships constructed on or after 1 January 2011 where approximately a 20% reduction level will be achieved comparing to the current legislation and Tier I. Tier III applies to the marine diesel engine installed on ships constructed on or after 1 January 2016, subject to some exemptions, operating in an Emission Control Area.

The highest sulphur content permitted in ship fuel will reduce globally as of 1 January 2012 from 4.5% to 3.5% and as of 1 January 2020 to 0.5%. Sulphur content allowed in Sulphur Emission Control Areas (SECA) that currently include the Baltic Sea, the North Sea and the English Channel will decrease as of 1 July 2010 from 1.5% to 1.0% and as of 1 January 2015 to 0.1%. In addition, the sulphur content of fuel used at port areas was decreased to 0.1% starting from 1 January 2010.

2.3. Traffic Growth

The effect of traffic growth on externalities is calculated with a constant annual growth rate through the timeline. The estimates of the future growth of maritime traffic include annual growth rates of 2.5% for cargo vessels and 3.9% for passenger vessels (Cofala *et al.* 2007) using the assumptions of the TREMOVE European transport model which are at the low end of the range of projections. The IMO GHG study (Skjølsvik *et al.* 2000) assumes an average growth rate of 3% per year between 2000 and 2030. A study by Corbett *et al.* (2007) comes up with an annual growth of 4.1% in the same period for the base case scenario. This study uses an average annual growth rate of 3.5% until 2030 for both passenger and cargo vessels.

2.4. Ship Renewal

Three CO_2 scenarios defined above are calculated with an annual ship renewal rate of 2% which leads to a ship age of 28 years after which the vessel is removed from traffic. Renewal has been taken into account after 1 January 2011 when Tier II entered in force. New ships are assumed to comply with the current Tier regulation prevailing at the time of renewal. Also, the ships introduced as part of the annual traffic growth are assumed to be new ships. This leads to an overestimate of the shares of Tier II and Tier III ships because in practice vessels that are part of the renewal and traffic growth can also be slightly older ships and this in turn leads to the underestimation of NO_x externalities. It is also expected that the Baltic Sea will have been nominated as a special area in IMO for NO_x emissions (NECA) before 2016. Potential effects on other pollutants by the renewal of ships and changing fuel consumption are not included in the calculations. It is assumed that Tier II ships produce 20% less and Tier III ships – 80% less NO_x than Tier I ships.

3. Results and Discussion

The estimated externalities calculated for all vessels visiting the eight ports of the Gulf of Finland are plotted per compound (CO_2, SO_2, CO, HC, PM and NO_x) in Fig. 2a. In the case of CO_2, three scenarios are shown based on the potential cost of t CO_2 (Scenario 1: €32, Scenario 2: €19 and Scenario 3: €9). Fig. 2b shows the total externalities summing all compounds except for CO_2, which is again separated into three scenarios to show the impact of the price of t CO_2 on the total estimated externalities.

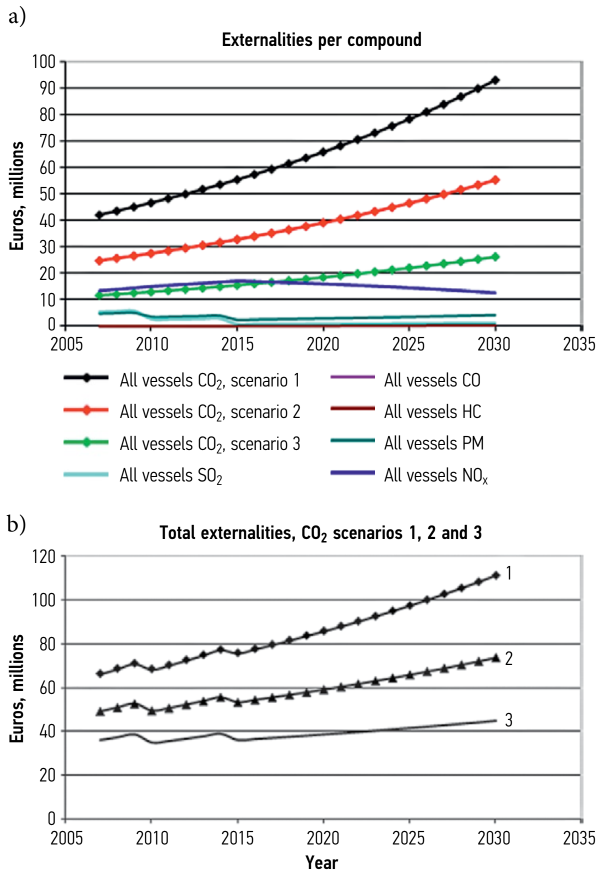

Fig. 2. Externalities: a – externalities (millions of €) of all vessels calculated for each compound and for three separate CO_2 scenarios (cost of t CO_2 as Scenario 1: €32, Scenario 2: €19 and Scenario 3: €9); b – total externalities (in millions of €) for three CO_2 scenarios

Fig. 3 evaluates the impact of changes in the annual traffic growth (concerning NO_x, PM and SO_2) and ship fleet renewal rate (concerning NO_x) on the resulting externalities using different CO2 scenarios (combinations of the traffic growth rate and/or fleet renewal rate). For NO_x (Fig. 3a), a traffic growth rate of 3.5% is combined with 1, 2 and 3% fleet renewal rates causing a 20% decrease in the externalities of the year 2030 for an increase in every 1% of the renewal rate. Finally, a higher traffic growth rate of 5% is combined with a fleet growth rate of 3% which causes no significant changes in externalities in 2030. For PM and SO_2 (Fig. 3b), by 2030, traffic growth rates of 1%, 3.5% and 5% will have resulted in the externalities of €2.5 million, €4.3 million and €6 million for PM, and €0.5 million, €1.1 million and €1.5 million for SO_2 respectively.

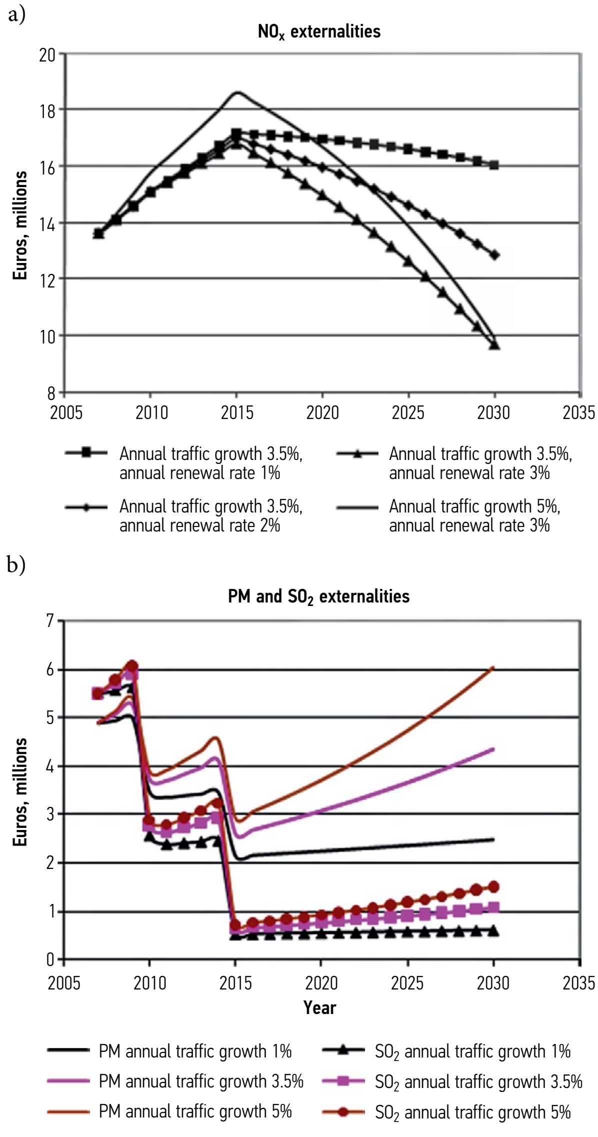

Fig. 3. Externalities: a – NO_x externalities (millions of €) calculated applying different rates of renewal and traffic growth (%); b – PM and SO_2 externalities shown with a varying annual rate of traffic growth (%)

3.1. Comparison of Previous Estimates

For each pollutant emissions at ports contributed about 50% of the total emissions at all Finnish ports. When compared to the reported ship originated emissions for 2007 at the Port of Helsinki, the emissions calculated in this study are a slight underestimate with an error of 20% for all pollutants except for CO_2, PM and SO_2 which are overestimated in this study (Mäkelä *et al.* 2008). For CO_2, PM and SO_2, the error is about 15%, 25% and 40% respectively. These errors in port emissions are most likely due to the applied ship categorizations as well as the use of average operation and emission factors. The overestimation of CO_2, SO_2 and PM emissions can be explained by the large amount of passenger ships calling at the Port of Helsinki with considerably shorter times at port than the assumed average of 7 hours and the use of low sulphur fuel. The share of externalities allocated for traffic to Finnish ports in the Gulf of Finland is about 40% of the total (Kalli, Tapaninen 2008).

The contribution of carbon monoxide (CO) and hydrocarbon (HC) emissions to externalities is very small (Fig. 2a) and will not play a significant role in the future cost estimates up to 2030.

3.2. NO_x Emissions

Following CO_2, NO_x has the highest estimate of externalities. The increase in NO_x emissions is predicted to slow down in the Baltic with the introduction of Tier II (1 January 2010) applying to new ships worldwide and eventually begin to decrease with the introduction of Tier III (1 January, 2016) regulations applying to new ships travelling through the emission control area such as the Baltic (IMO, MARPOL Annex VI). Externalities are estimated to show some decline from €17 million in 2015 to €13 million in 2030 (Fig. 2a). The introduction of Tier II in 2010, seen as a change in the slope (Figs 2a, 3a), is not predicted to have a real impact on the externalities because its effect is masked by an increase in traffic growth. The estimated gradual decline in NO_x emissions resulting from policy changes will be counteracted by PM, SO_2 and CO_2 emissions in the total externalities.

Tier III will result in a drop in emissions and, therefore, in externalities (Figs 2a, 3a) if the Baltic Sea is made into a NO_x ECA in 2016 as has been planned. It is supposed that in the case of Tier III, traffic growth and the renewal rate will consist of Tier III compatible ships only after 2016. Therefore, it is assumed that Tier III regulations will not be circumvented by replacing the Gulf of Finland fleet with old ships that are not regulated under Tier III. If this does occur, the curve of NO_x externalities would not begin to decrease at Tier III (2016). Instead, this deflection point would be moved into the future and eventually no non-Tier III ships would be brought into the area.

Cost Efficiency of NO_x Reduction Techniques and Policies

Fig. 3a shows the impact of changes in traffic growth and fleet renewal rates on NO_x externalities. The growth rate used in this study has been estimated to be 3.5%. A faster renewal rate (varying from 1% to 3%) would greatly decrease the estimates of externalities with an increase of 1% in the renewal rate, decreasing the externalities by approximately 20%. An increase in the fleet growth rate from 1.5% to 5% per year (instead of 3.5%), while keeping the renewal rate at 3% for both cases, still predicts externalities of approximately €9.5 million by 2030 (Fig. 3a). Therefore, NO_x externalities are more impacted by the renewal rate of the fleet than by the annual growth assumed via new ships of the Gulf of Finland fleet. This shows that retrofitting older engines is the key to decreasing NO_x emissions by 2020. The reduction in NO_x emissions is more dependent on the scrapping rate and on a spontaneous use of measures for NO_x abatement on board ships built prior to 2016, rather than with the introduction of brand new Tier II and III ships.

Studies have found that the socio-economic benefits (and the lower costs to society) from a reduction in NO_x and ozone damage are greater, as long as pay-off times are about 10 years, than the estimated costs, and therefore it is more cost efficient to reduce emissions from maritime transport than to cut emissions from land-based sources even further (Cofala *et al.* 2007). The ENTEC (2005) estimate for these costs in €/ton of NO_x abated by SCR inside SECA is €543 for small new vessels and €398 for large ones, and €613 for the retrofit of small vessels and €443 for the large. In addition to these technologies, Kågeson (2009) proposes the use of a charge of NO_x-differentiated emissions along the lines of the current Norwegian NO_x charge over economic instruments such as emissions trading, differentiated fairway and port dues and emissions charging. Kågeson (2009) estimates resulting cuts of NO_x emissions from ships in the Baltic Sea by ~60% which would correspond to an annual reduction of approximately 270000 t from the expected business-as-usual level of ~460000 t in 2015.

3.3. PM and SO_2 Emissions

SO_2 and PM emissions from shipping show the largest drop in quantity between 2007 and 2015 due to the upcoming MARPOL Annex VI regulations for sulphur content in marine fuels with a global decrease in fuel sulphur content from 1.5 % to 1.0 % in 2010 and further to 0.1 % in 2015 in the Baltic and other SECA (Figs 2a, 3b). Although both show a decrease in this time period, SO_2 and PM externality curves differ as after SO_4 particles are removed following a reduction in fuel sulphur content, certain particles will always be produced and thus PM emissions cannot be fully eliminated.

A decrease in SO_2 and PM externalities is especially large in 2010 due to further regulations affecting SO_2 emissions in the Baltic and the Gulf of Finland (Fig. 3b). The EU provision for decreasing the sulphur content of fuel for ships at berth to 0.1%–S will be in effect at all EU ports after 1 January 2010. Therefore, while at sea the content of sulphur fuel drops by a third from 1.5% to 1% in 2010, the externalities decrease by a half due to the 0.1% required for Finnish harbours, as harbour costs are the highest considering the spatial allocation of emissions. After the final decrease in 2015, SO_x and

PM emissions and their externalities will have begun to increase again with traffic growth. After 2015, S cost will be small in comparison with CO_2 and NO_x costs. The range of the traffic growth rate of 1% to 5% (Fig. 3b) gives a range of externalities of €2.5–6 million in PM and €0.5–1.5 million in SO_2.

Cost Efficiency of EU and IMO Regulations on Sulphur in Ship Fuel

The calculation of externalities also reveals the economic efficiency problem of reducing the sulphur content of marine fuels to 0.1%–S in SECA instead of 0.5%–S, which will be the global limit in 2020.

There was a minor increase in fuel costs after 1 January 2010 due to the EU regulation on sulphur in ship fuels at berth. Almost the same monetary value is saved in externalities, and therefore it can be argued that regulation is cost effective. The 2015 IMO MARPOL 73/78 Annex VI will decrease the sulphur limit to 0.1% in the Gulf of Finland, and this will greatly increase fuel costs as complying with Annex VI will in practice mean switching from cheaper heavy fuel oil to more expensive distillates (marine gas oil, MGO). The total fuel cost will have increased by €50 million in 2015, whereas the decrease obtained in externalities is only €10 million. Therefore, for the Gulf of Finland, the cost efficiency of this MARPOL SECA regulation is very poor, especially since it can be argued that the greatest health benefits will be achieved through the 2010 EU regulation on harbour emissions.

3.4. CO_2 Emissions

Fig. 2b shows totals of all compounds with the three different CO_2 scenarios. The calculation of externalities per compound shows the comparatively large influence of CO_2 emissions (Figs 2a, 2b). The estimated t CO_2 cost range of €9–32 makes a large difference in the externalities estimated for 2030 and gives a range of €45–111 million. This is at least 3 times higher than the sum of the second externality in order (NO_x) which is €13 million. With CO_2 costing €32 or €19, the trend of externalities is dominated by CO_2 and will increase to 2030 (Fig. 2b). Only at €9 can the slope of the CO_2 increase be slowed down significantly. The question of CO_2 is central to the externalities debate and to decreasing the overall externalities total; CO_2 from shipping must be controlled in the future. The current IMO work includes technical options that can at best remove approximately 20% of CO_2 emissions per ship (IMO MARPOL 73/78 Annex VI). Limiting ship speed can have a large impact on reducing CO_2 emissions.

3.5. The Structure of the Gulf of Finland Ship Fleet

Fig. 4 shows changes in the total Gulf of Finland ship fleet with the introduction of Tier II and Tier III regulations (IMO MARPOL 73/78 Annex VI). The renewal rate of the fleet is an especially important factor because in the future Tier II and III will have an effect on NO_x emissions due to the requirement that ships built after

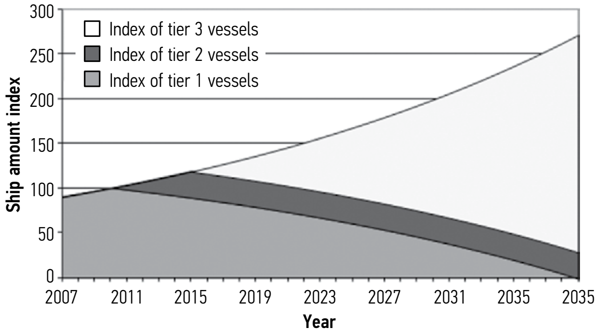

Fig. 4. Changes in the structure of the Gulf of Finland ship fleet over time due to the introduction of Tier II and Tier III. The annual growth rate is assumed to be 3.5% with 2% used for the renewal rate

2010 must produce 20% less NO_x emissions than Tier I that has been in force as of 1 January 2000. With an assumed annual fleet growth of 3.5% and a renewal rate of 2%, Tier I ships will have run out in approximately 28 years (by 2039). Along with the introduction of Tier III in 2016, building more Tier II ships will not be cost effective with respect to the long lifespan of ships.

4. Conclusions

The total external cost of ship-originated emissions in the Gulf of Finland will be €36–76 million in 2015 and will have increased up to €45–111 million by 2030. The majority of externalities are produced by CO_2 emissions. Therefore, the final cost of t CO_2 will decide the overall trend of the externalities curve. Only t CO_2 costs of around €9 will be able to level off the estimates of total externalities from an increasing trend. The price of CO_2 entails considerable uncertainty, including large fluctuations in calculating estimates of externalities in the recent past. The trend seems to be towards lower numbers and the final number could be well under €10. Now, CO_2 appears to be so overwhelming that it gives the impression that other compounds such as NO_x, SO_2 and PM are not significant. This would be a misguided conclusion due to the large adverse health and environmental impacts of the other pollutants.

In addition to forthcoming IMO regulations (IMO MARPOL 73/78 Annex VI), the future emissions of NO_x are greatly impacted by still unknown factors such as the ship fleet renewal rate. These factors cause the future externalities to be estimated much higher for NO_x than for SO_2 and PM. There are several efficient technologies available to deal with NO_x emissions. Nevertheless, today only SCR complies with Tier III, which will increase operational costs, but due to the long lifespan of ships there is a risk that traffic growth and the renewal of ships will consist of Tier I and II ships only turning NECAs (such as the Baltic Sea) into the last service areas for old ships before scrapping. To prevent this, it would be important to develop NO_x control systems that would also affect the ships built before 2016. Such systems could be, for example, differentiated fairway and harbour fees and even emission trading.

The planned policies regulating the S-content of fuel by IMO and the EU will be very effective in removing SO_2 pollution and will have the greatest impact. This is reflected in the estimated decrease in SO_2 externalities, and therefore SO_2 is not expected to be a significant factor in the future. PM will always be produced to a certain extent, and as PM (particles less than 2.5 μm) are especially harmful to health, PM costs will remain high. Through the EU directive on fuel S-content in harbours (down to 0.1%), PM will be minimized as much as possible. The MARPOL SECA policy of reducing fuel S-content to 0.1% by 2015 appears to be ineffective when comparing additional fuel cost to cost savings in externalities as it can be argued that the greatest health benefits will have already been achieved through the 2010 EU regulation on harbour emissions with a comparatively low additional fuel cost after 2010.

This study has shown the importance for air emissions of renewing the ship fleet. However, life-cycle analysis of the environmental effects of building new ships and recycling old ships is needed to get a complete picture. The introduction of more energy efficient, less polluting ships is slow and therefore has not been a strong method of reducing emissions from ships. If policies are introduced as incentives on environmental and economic grounds to increase the rate at which older ships are replaced with the new ones in the Gulf of Finland, is this actually an environmentally sound policy on the grounds of emissions produced in the process? Is it more cost effective to build new ships or refit the older ones (and prolong their lifespan) with regard to CO_2 emissions and their global impact? Future studies must consider the benefits gained from the faster introduction of new and cleaner ships against the CO_2 emissions produced by the current (older) ships and the emissions produced from scrapping and producing new ships.

As part of further future work to focus on, the methodology of current externalities still lacks the evaluation of environmentally important factors such as eutrophication. A solution in this case could be the evaluation of the monetary value of still healthy parts of the Baltic such as the Gulf of Bothnia. This requires the further development of water quality assessment systems to be able to provide a cost per ton of N (or P) released into the ecosystem to enable inclusion into externality models. In this way, the loss of such monetary value in the Gulf of Finland and other areas of the Baltic could be applied for calculating externalities. The challenge here is the complexity of the marine ecosystem where a ton of N will not cause the same amount of eutrophication in all locations, the impact of seasonality and the form of the released nitrogen. However, it may be possible to come to a shadow price as in the case of CO_2.

References

Bunkerworld. 2009. *Fuel prices – Rotterdam*. Available from Internet: http://www.bunkerworld.com

Cofala, J.; Amann, M.; Heyes, C.; Wagner, F.; Klimont, Z.; Posch, M.; Schöpp, W.; Tarasson, L.; Jonson, J. E.; Whall, C.; Stavrakaki, A. 2007. *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*. Final Report. International Institute for Applied Systems Analysis. Laxenburg, Austria. 64 p. Available from Internet: http://www.iiasa.ac.at/rains/reports/IR06-107_Ships.pdf

Corbett, J. J.; Winebrake, J. J.; Green, E. H.; Kasibhatla, P.; Eyring, V.; Lauer, A. 2007. Mortality from ship emissions: a global assessment, *Environmental Science and Technology* 41(24): 8512–8518. http://dx.doi.org/10.1021/es071686z

Corbett, J. J.; Koehler, H. W. 2003. Updated emissions from ocean shipping, *Journal of Geophysical Research* 108(D20): 4650. http://dx.doi.org/10.1029/2003JD003751

Corbett, J. J.; Fischbeck, P. S.; Pandis, S. N. 1999. Global nitrogen and sulfur inventories for oceangoing ships, *Journal of Geophysical Research* 104(D3): 3457–3470. http://dx.doi.org/10.1029/1998JD100040

Derwent, R. G.; Stevenson, D. S.; Doherty, R. M.; Collins, W. J.; Sanderson, M. G.; Johnson, C. E.; Cofala, J.; Mechler, R.; Amann, M.; Dentener, F. J. 2005. The contribution from shipping emissions to air quality and acid deposition in Europe, *Ambio* 34(1): 54–59.

Endresen, Ø.; Sørgård, E.; Sundet, J. K.; Dalsøren, S. B.; Isaksen, I. S. A.; Berglen, T. F.; Gravir, G. 2003. Emission from international sea transportation and environmental impact, *Journal of Geophysical Research* 108(D17): 4560. http://dx.doi.org/10.1029/2002JD002898

ENTEC. 2005. *Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 2b – NO_X Abatement*. Final Report. ENTEC UK Limited. 44 p. Available from Internet: http://ec.europa.eu/environment/air/pdf/task2_nox.pdf

European Commission. 2004. *EUR 21951 EN — ExternE – Externalities of Energy – Methodology 2005 Update*. (Eds Bickel, P.; Friedrich, R.). Luxembourg: Office for Official Publications of the European Communities. Available from Internet: http://www.externe.info/brussels/methup05a.pdf

European Commission. 1997. *External Costs of Transport in ExternE*. (Eds Bickel, P.; Schmid, S.; Krewitt, W.; Friedrich, R.). Publishable Report. Contract JOS3-CT95-0004. 20 p. Available from Internet: http://www.ocs.polito.it/biblioteca/mobilita/ExternalCosts.pdf

Eyring, V.; Kohler, H. W.; Van Aardenne, J.; Lauer, A. 2005. Emissions from international shipping: 1. The last 50 years, *Journal of Geophysical Research* 110: D17305. http://dx.doi.org/10.1029/2004JD005619

Cofala, J.; Amann, M.; Heyes, C.; Wagner, F.; Klimont, Z.; Posch, M.; Schöpp, W.; Tarasson, L.; Jonson, J. E.; Whall, C.; Stavrakaki, A. 2007. *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*. Final Report. IIASA Contract No. 06-107. Available from Internet: http://www.iiasa.ac.at/rains/reports/IR06-107_Ships.pdf

IMO (International Maritime Organization). *MARPOL 73/78 is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978*. Annex VI: Prevention of Air Pollution from Ships.

Kalli, J.; Tapaninen, U. 2008. *Externalities of Shipping in the Gulf of Finland until 2015*. Centre for Maritime Studies, University of Turku, Finland. 69 p.

Klemola, E.; Kuronen, J.; Kalli, J.; Arola, T.; Hänninen, M.; Lehikoinen, A.; Kuikka, S.; Kujala, P.; Tapaninen, U. 2009. A cross-disciplinary approach to minimising the risks of maritime transport in the Gulf of Finland, *World Review of*

Intermodal Transportation Research 2(4): 343–363. http://dx.doi.org/10.1504/WRITR.2009.026212

Kågeson, P. 2009. Market-based instruments for NO_x abatement in the Baltic Sea, *Air Pollution and Climate Series*, Vol. 24. 38 p.

Lloyd's Register. 2009. *Fairplay Research*.

Lloyd's Register. 1995. *Marine Exhaust Emissions Research Programme*. London.

Mäkelä, K.; Järvi, T.; Tuominen, A.; Pääkkönen, E. 2008. *Suomen vesiliikenteen päästöjen laskentajärjestelmä MEERI 2006*. 47 p. Available from Internet: http://lipasto.vtt.fi/meeri/meeri2006raportti.pdf (in Finnish).

MINTC (Ministry of Transport and Communications of Finland). 2003. *Liikenteen päästökustannukset. Päivitys ja yhteenveto*. Report B29/2003. Helsinki, Finland (in Finnish).

Otterström, T.; Gynther, L.; Vesa, P. 1998. *Halukkuus maksaa puhtaammasta ilmanlaadusta*. Selvitys 60P00678. SIHTI 2-tutkimusohjelman projekti 130T. Energia-Ekono Oy, Espoo (in Finnish).

Skjølsvik, K. O.; Andersen, A. B.; Corbett, J. J.; Skjelvik, J. M. 2000. *Study of Greenhouse Gas Emissions from Ships*. Final Report to the International Maritime Organization. MT Report: MT00 A23-038. Trondheim, Norway. 170 p. Available from Internet: http://unfccc.int/files/methods_and_science/emissions_from_intl_transport/application/pdf/imoghgmain.pdf

Stipa, T.; Jalkanen, J.-P.; Hongisto, M.; Kalli, J.; Brink, A. 2007. *Emissions of NO_x from Baltic Shipping and First Estimates of Their Effects on Air Quality and Eutrophication of the Baltic Sea*. Report. ShipNODeff Programme. 31 p. Available from Internet: http://www.helcom.fi/stc/files/shipping/NOx%20emissions.pdf

Wahlström, J.; Karvosenoja, N.; Porvari, P. 2006. *Ship Emissions and Technical Emission Reduction Potential in the Northern Baltic Sea*. Reports of Finnish Environment Institute, Vol. 8. 70 p. Available from Internet: http://www.environment.fi/download.asp?contentid=55273&lan=en

APPENDIX

Table. Variables used for calculating emissions in the Gulf of Finland and data on traffic

Cargo ships							
Category	1	2	3	4	5	6	7
Average installed power [kW]	1352	1194	2658	5465	9371	12257	19172
Main engine load, open sea	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SFC [g/kWh] 2-stroke main engine	200	200	200	200	200	200	200
SFC [g/kWh] 4-stroke main engine	200	200	200	200	200	200	200
Auxiliary power [kW]	230	346	520	786	1122	1447	1770
SFC [g/kWh] auxiliary engine	180	180	180	180	180	180	180
Speed (80% load) [km/h]	21	21	25	30	32	33	37
Time at port	13.2	14.6	18.5	17.8	42.9	22.8	35.4
Aux load in port	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Aux load in open sea	0.2	0.2	0.2	0.2	0.2	0.2	0.2
NO_x factor 2 stroke 80% load [g/kWh]	17.7	17.7	17.7	17.7	17.7	17.7	17.7
NO_x factor 4 stroke 80% load [g/kWh]	14	14	14	14	14	14	14
NO_x factor 4 stroke 20% load [g/kWh]	16	16	16	16	16	16	16
SO_2 factor [g/kg] S-% = 1.33	26.5	26.5	26.5	26.5	26.5	26.5	26.5
CO_2 factor [g/kg]	3231	3231	3231	3231	3231	3231	3231
CO [g/kWh] 2 stroke 80% load	0.6	0.6	0.6	0.6	0.6	0.6	0.6
CO [g/kWh] 4 stroke 80% load	1	1	1	1	1	1	1
CO [g/kWh] 4 stroke 20% load	2	2	2	2	2	2	2
PM [g/kWh] 2 stroke 80% load	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PM [g/kWh] 4 stroke 80% load	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PM [g/kWh] 4 stroke 20% load	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC [g/kWh] 2 stroke 80% load	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC [g/kWh] 4 stroke 80% load	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC [g/kWh] 4 stroke 20% load	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Share of 4 stroke engines [%]	97	72	76	25	10	8	0
Share of 2 stroke engines [%]	3	28	24	75	90	92	100
Passenger ships							
Category	1	2	3	4	5	6	7
Average installed power [kW]	640	14291	18666	17348	5474	13955	25954
Main engine load, open sea	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SFC [g/kWh] main engine	180	180	180	180	180	180	180
Auxiliary power [kW]	230	346	520	786	1122	1447	1770
SFC [g/kWh] Auxiliary engine	180	180	180	180	180	180	180
Speed (80% load) [km/h]	24	69	67	54	29	37	40
Time at port	7	7	7	7	7	7	7
Aux load in port	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Aux load in open sea	0.8	0.8	0.8	0.8	0.8	0.8	0.8
NO_x factor 4 stroke 80% load [g/kWh]	14	14	14	14	14	14	14
NO_x factor 4 stroke 20% load [g/kWh]	16	16	16	16	16	16	16
SO_2 factor [g/kg] S-% = 0.43	8.53	8.53	8.53	8.53	8.53	8.53	8.53
CO_2 factor [g/kg]	3225	3225	3225	3225	3225	3225	3225
CO [g/kWh] 4 stroke 80% load	1	1	1	1	1	1	1
CO [g/kWh] 4 stroke 20% load	2	2	2	2	2	2	2
PM [g/kWh] 4 stroke 80% load	0.3	0.3	0.3	0.3	0.3	0.3	0.3
PM [g/kWh] 4 stroke 20% load	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC [g/kWh] 4 stroke 80% load	0.4	0.4	0.4	0.4	0.4	0.4	0.4
HC [g/kWh] 4 stroke 20% load	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Share of 4 stroke engines [%]	100	100	100	100	100	100	100
Share of 2 stroke engines [%]	0	0	0	0	0	0	0