Baltic NECA – economic impacts

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Abstract

Eutrophication of the Baltic Sea is a major problem and shipping contributes to the eutrophication through NOx emissions. That is why a NOx Emission Control Area (NECA) status for the Baltic Sea is included in the HELCOM Baltic Sea Action Plan (BSAP).

IMO’s MARPOL Annex VI, adopted by MEPC 58 in October 2008 includes a reduction scheme for new ships. The Tier standards (Tier I, Tier II and Tier III) define emission levels for marine diesel engines installed on ships after certain construction year. However, the last and most strict NOx emission standard, Tier III, requires a designation of a sea area as Emission Control Area where Tier III must be complied.

Quantitative estimation of the additional costs of the Baltic NECA is based on the present Baltic fleet and on its NOx emissions and fuel consumption. The emissions are estimated in the “Shipping-induced NOx and SOx emissions – Operational monitoring network” (SNOOP) project (Central Baltic INTERREG IV A Programme 2007–2013). The investment and operational costs are based on the estimations provided by the engine manufacturer Wärtsilä. The capital costs are estimated based on the future scenario of installed engine power (kW) in new ships (including both main and auxiliary power). Fleet renewal and traffic growth in the future scenarios are assumed to be new ships.

The raw data for the base year 2008 includes more than 6,000 ships from which a major part sails only few days in the Baltic. In practice, if a Baltic NECA will be established, there will be Tier III ships that are mainly sailing in the Baltic and the amount of ships that rarely visit the Baltic will be reduced. Therefore two different CAPEX scenarios are created. In the scenario 1 the total additional cost of the Tier III will be 76.6 million Euros in 2020 and 289 million Euros in 2030. In the scenario 2 the costs will be 55.6 and 206 million Euros respectively.

The current technology that meet the MARPOL Annex VI Tier III NOx emission standards are either selective catalytic reduction (SCR) or gas engine and fuel conversion. SCR is an exhaust gas after treatment technology which has a NOx abatement capability more than 80 % and it is the most likely technology to be used in new ships after 1.1.2016 to comply with Tier III standard. SCR has to be installed separately for each engine of a ship and it needs urea to work. Gas engine and fuel conversion are methods that in principle means the use of liquefied natural gas (LNG) as fuel. It can be predicted that the infrastructure required for LNG delivery to the ships will be built in the future.

The selective catalytic reduction (SCR) is the only technology today which meets the Tier III reduction requirements and from which we know enough to make abatement cost estimates. Cost calculations show that abatement of one tonne of NOx will cost 787–4,699 Euros (2,585–15,440 Euros per abated tonne of nitrogen) depending on the type of a ship and the method of calculation. However, the average cost is about 1,316–1,843 Euros per tonne NOx (4,325–6,059 Euros per tonne of nitrogen). Previous figures are calculated with
interest rate of 10% for the investment of SCR. With 5% interest rate the abatement costs will decrease to 695–3,176 Euros (2,283–10,436 Euros per abated tonne of nitrogen) and the average cost 1,022–1,362 Euros per tonne NOx (3,360–4,476 Euros per tonne of nitrogen) respectively.

Comparison of the cost efficiency of nitrogen abatement from the shipping to other sectors is difficult due to the fact that the estimation of deposition of ship originated NOx onto the Baltic Sea is challenging, and the cost and impact to environment of one tonne of nitrogen from shipping, agriculture and waste water treatment is different and uncertain. However, the estimated abatement cost of nitrogen from especially the ro-ro, ropax and container vessels is low, the unit cost may be below 3,000 Euros per tonne of nitrogen.

According to our estimations the rise in freight rates of new vessels due to the use of Tier III NOx emission reduction equipment will be depending on vessel type and size from 2.0 % to 4.6 %. There are methods to compensate the additional costs for the shipowners for example economic incentives. Internalizing the HELCOM recommendation 28E/13 to fairway fee system of the HELCOM countries could give significant compensations extending to even 45 % of the annual additional costs of the use of SCR. The potential for modal shift from sea transport to road or rail transport caused solely by the NOx regulations will be very small or non-existent.
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1 Introduction

Eutrophication is a major problem in the Baltic Sea. Since the 1900s, the Baltic Sea has changed from an oligotrophic clear-water sea into a eutrophic marine environment. Eutrophication is a condition in an aquatic ecosystem where high nutrient concentrations stimulate the growth of algae which leads to imbalanced functioning of the system, such as oxygen depletion with recurrent internal loading of nutrients and death of benthic organisms, including fish.

Excessive nitrogen and phosphorus loads coming from land-based and sea-based sources, within and outside the catchment area of the Contracting States, are the main cause of the eutrophication of the Baltic Sea. The average nitrogen load between 2000–2006 was approximately 650,000 tonnes. About 75 % of the nitrogen entered the Baltic Sea as waterborne input and 25 % as airborne input. Agriculture and managed forestry contributed almost 60 % of the waterborne nitrogen inputs to the sea, 28 % entered from natural background sources and 13 % came from point sources. The airborne nitrogen input has been calculated as direct atmospheric deposition on the Baltic Sea. The total annual NOx emissions from ships in the Baltic are at more than 393,000 tonnes in 2008 (http://www.helcom.fi/BSAP_assessment/ifs/ifs2009/en_GB/Ship_emissions_in_Baltic_Sea_Area_in_2008/). This figure is higher than any previous estimates and is comparable to the combined land-based NOx emissions from Denmark and Sweden.

Baltic Sea NECA is included in the HELCOM Baltic Sea Action Plan (BSAP) and the subject was further discussed in HELCOM Moscow Ministerial Meeting in May 2010 where it was stated that they agree “to work towards submitting, preferably by 2011, a joint proposal by the Baltic Sea countries to the IMO applying for a NOx Emission Control Area (NECA) status for the Baltic Sea, taking into account the results of the study by HELCOM on economic impacts of a Baltic Sea NECA and to welcome and support the idea of a NOx Emission Control Area in other sea areas, in particular with regard to the North Sea.”

MARPOL Annex VI, adopted by MEPC 58 in October 2008 includes a reduction scheme for new ships. The Tier standards (Tier I, Tier II and Tier III) define emission levels for marine diesel engines installed on ships after certain construction year. Details of the IMO’s NOx emission regulation with the implementing dates are shown in the Appendix 2. However, the last and most strict NOx emission standard, Tier III, requires a designation of a sea area as Emission Control Area where Tier III must be complied. This study shows a quantitative method to estimate the costs of NOx abatement and additional costs for shipping if the Baltic Sea will be designated as a NOx emission control area (NECA).

This research study indicate that if the Baltic Sea will not be designated as a NECA then NOx emission from shipping will continue to increase together with the traffic growth. Introduction of Tier III reduction scheme compares to 80 % reduction from Tier I level for new ships which would be enough to turn the NOx trend to decrease and halve the NOx emissions of shipping by 2040.
There has been discussion about the cost effectiveness of the methods how and from which sector it would be most efficient to cut emissions and to prevent nitrogen flow to the Baltic Sea. However, this study does not answer the question from which sector the abatement would be most efficient from the environmental point of view. In this study we present an estimate of the NOx and nitrogen abatement costs of different type of ships with the designation of the Baltic Sea as a NECA area. Baltic NECA would require an installation of specific abatement technology onboard a ship.
2 Material and methods

This research study is based on both qualitative and quantitative methods. Research follows the principles of mixed method research where results of qualitative interviews and surveys are used to develop a quantitative method for the estimation of the additional costs of NECA to the Baltic Sea shipping.

2.1 Technology which meet the Tier III emission standard

The current technology that meet the MARPOL Annex VI Tier III NOx emission standards are (personal discussion, Göran Hellen, Wärtsilä, 12.5.2010):

1. Selective catalytic reduction (SCR)
2. Gas engine and fuel conversion

SCR is an exhaust gas after treatment technology which has a NOx abatement capability of more than 80 % and it is the most likely technology to be used in new ships after 1.1.2016 to comply with Tier III standard. SCR has to be installed separately for each engine of a ship and it needs urea to work. Gas engine and fuel conversion are methods that in principle means the use of liquefied natural gas (LNG) as fuel. LNG as a fuel produces NOx emissions much less than use of diesel fuels and therefore complies with the Tier III. Even if the technology is already available there are major challenges in the infrastructure of fuel delivery to ships. Lack of infrastructure and the fact that there is no fuel, which could be considered as marine LNG, make it impossible to estimate the additional costs. It can be predicted that the infrastructure will be built in the future but due to the lack of it the SCR is the only method today that is able to provide the needed abatement efficiency. This is why the cost estimation is done only for the SCR.

Engine technology in the field is developing towards better environmental performance. However, there are no other technologies provided by Wärtsilä at the moment that would comply with the MARPOL Annex VI Tier III. Engine manufacturers are constantly developing new technologies and there are several of them that might be possible options if they prove to be more economical than SCR. However, the present experience indicates that to comply with Tier III it must be a combination of several different methods listed below (personal discussion, Göran Hellen, Wärtsilä, 12.5.2010):

1. High pressure turbocharger (TC) sys. (2-stage) (ca. NOx -40 %)
2. Low NOx combustion tuning (ca. NOx -10 %)
3. EGR system (ca. NOx -60 %)
4. Charge air humidification (ca. NOx -40 %)
5. Water Fuel Emulsion (ca. NOx -25 %)
6. Direct Water Injection (ca. NOx -50 %)
2.2 NECA additional costs for the Baltic shipping

Quantitative estimation of the additional costs of the Baltic NECA is based on the present Baltic fleet and on its NOx emissions and fuel consumption. The emissions of the Baltic shipping are estimated in the project “Shipping-induced NOx and SOx emissions – Operational monitoring network” (SNOOP). The SNOOP project is implemented in collaboration with nine organizations from Finland and Estonia and it is financed by Central Baltic INTERREG IV A Programme 2007–2013 and Centre for economic development, transport and the environment (ELY) of Southwest Finland. The SNOOP emission estimation is based on the automatic identification system (AIS) data covering the whole Baltic Sea. This estimation can be considered as the best available information source for the atmospheric emissions of shipping in the area. SNOOP model provides estimation for the NOx emissions and for the fuel consumption which are used as raw data for the cost estimation scenarios of this study. The SNOOP emission model is described in the article by Jalkanen et al. (2009).

2.2.1 Ships included in the cost estimation

We have extracted from the SNOOP results 12 ship types presented in the Table 2.1. These 12 ship types are defined in the Lloyd’s Register of Ships and utilized in the emission scenario calculations. The 12 ship types cover the 5 types listed by HELCOM CG in task 1 B:

1. Dry cargo ship
2. Oil tanker
3. Ropax ship
4. Ro-ro vessel
5. Container vessel

Table 2.1 shows all ships that have visited in the Baltic Sea in 2008 belonging to the 12 categories. It also shows how much engine power each ship type is representing. Figure 2.1 summarizes the fuel consumption of all ship types for which the emissions are estimated in the SNOOP project. The 12 ship types included in this study represents 84 % of the total atmospheric NOx emissions of shipping in the Baltic.
Table 2.1 Ship type details (Baltic Sea shipping in 2008).

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Ship type code</th>
<th>Number of ships visited in the Baltic in 2008</th>
<th>Installed main engine power (kW)</th>
<th>Installed auxiliary engine power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reefer ship</td>
<td>RC</td>
<td>338</td>
<td>2 515 171</td>
<td>732 664</td>
</tr>
<tr>
<td>General cargo ship</td>
<td>GC</td>
<td>2 172</td>
<td>5 546 590</td>
<td>1 302 312</td>
</tr>
<tr>
<td>Product tanker</td>
<td>T_PROD</td>
<td>270</td>
<td>1 854 899</td>
<td>362 987</td>
</tr>
<tr>
<td>Container ship</td>
<td>CONT</td>
<td>324</td>
<td>5 283 246</td>
<td>1 158 465</td>
</tr>
<tr>
<td>Chemical tanker</td>
<td>T_CHEM</td>
<td>842</td>
<td>5 126 000</td>
<td>1 508 702</td>
</tr>
<tr>
<td>Crude oil tanker</td>
<td>T_CRD</td>
<td>332</td>
<td>4 254 381</td>
<td>761 446</td>
</tr>
<tr>
<td>Bulk ship</td>
<td>BULK</td>
<td>936</td>
<td>7 137 109</td>
<td>1 104 540</td>
</tr>
<tr>
<td>RO-RO ship</td>
<td>RORO</td>
<td>165</td>
<td>1 744 183</td>
<td>442 945</td>
</tr>
<tr>
<td>ROPAX ship</td>
<td>ROPAX</td>
<td>226</td>
<td>3 437 141</td>
<td>774 072</td>
</tr>
<tr>
<td>Vehicle carrier</td>
<td>V</td>
<td>208</td>
<td>2 622 450</td>
<td>502 378</td>
</tr>
<tr>
<td>Liquid petroleum gas tanker</td>
<td>T_PLG</td>
<td>119</td>
<td>611 003</td>
<td>171 076</td>
</tr>
<tr>
<td>Cruise ship</td>
<td>PAS_CR</td>
<td>80</td>
<td>2 016 636</td>
<td>350 079</td>
</tr>
</tbody>
</table>

Figure 2.1 Fuel consumption and number of ships visited in the Baltic Sea in 2008 (12 ship types which are included in this study). Source: SNOOP.
2.3 Investment and operational costs of Tier III

The NECA application (MEPC 59/6/5) and ENTEC (2005) study include an estimation of the investment and operation costs of the equipment needed to fulfil the Tier III emission standard. A survey to Wärtsilä was created to update and collect more detailed information about costs of the NOx abatement technology. Marine engine manufacturer Wärtsilä answered the survey and wants to highlight that “the given information is very much generalized and therefore cannot be used in any individual case. Another note; some of the technologies (e.g. SCR for diesel engines with pre-TC SCR / high sulphur) are not yet so mature or developed as the traditional SCR applications. A lot of efforts are expected to be put on the development of these techniques, and clear improvement in the competitiveness should be reached. This means that the costs represent more the current cost level, not as expected for Tier III solutions closer to 2016.”

The pre-TC (pre-turbocharger) SCR is a future design of SCR which allows the use of high sulphur fuels and scrubbers to simultaneously abate NOx and SOx emissions. Use of high sulphur fuels means that the SCR needs to be designed accordingly, and is somewhat more expensive (see Table 2.2). Also the temperature requirement is higher, up to 350 °C. This is to be taken up in the engine tuning along with other requirements. The pre-TC SCR installations is likely to provide the best combination in terms of engine efficiency and emissions but is subject to overall design and SCR integration to the engine.

In general, SCR hardware cost estimation by Wärtsilä is very close to the costs given in MEPC 59/6/5. Table 2.2 and Table 2.3 comprise the results of the survey and compare them to MEPC 59/6/5 and ENTEC (2005). Due to up to date information and which takes into account the specific nature of the Baltic Sea shipping, the values from the Wärtsilä are used in the cost estimations of this study.
<table>
<thead>
<tr>
<th>Abatement technology</th>
<th>Example values from other sources</th>
<th>Wärtsilä’s estimation for hardware costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCR Hardware costs</td>
<td>MEPC 59/6/5 USA Canada ECA application</td>
<td>€/kW (for distillate fuels &lt; 1 % S) for newbuildings</td>
</tr>
<tr>
<td>ENGINE SPEED</td>
<td>ENGINE SIZE RANGE (KW)</td>
<td>€/kW</td>
</tr>
<tr>
<td>Medium</td>
<td>4,500–18,000</td>
<td>32–64</td>
</tr>
<tr>
<td>Slow</td>
<td>8,500–48,000</td>
<td>36–59</td>
</tr>
<tr>
<td>SCR Hardware costs when a ship already has a sulphur scrubber</td>
<td>Medium</td>
<td>4,500–18,000</td>
</tr>
<tr>
<td>Slow</td>
<td>8,500–48,000</td>
<td>not available</td>
</tr>
</tbody>
</table>

Currency exchange rate: 1 EUR = 1.2894 USD (average rate in August 2010)
### Table 2.3 SCR operation costs.

<table>
<thead>
<tr>
<th>Abatement technology</th>
<th>Example values from other sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operation costs to meet Tier III standard</strong></td>
<td></td>
</tr>
<tr>
<td>Urea costs</td>
<td>1.18 €/gallon (32.5 per cent urea)</td>
</tr>
<tr>
<td>ECA application</td>
<td></td>
</tr>
<tr>
<td><strong>Urea dosing figure, per cent of the brake-specific fuel consumption</strong></td>
<td>not available</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Expected lifetime of the equipment</strong></td>
<td>not available</td>
</tr>
<tr>
<td><strong>Rebuilding the SCR</strong></td>
<td>not available</td>
</tr>
<tr>
<td><strong>Cost of rebuilding</strong></td>
<td>not available</td>
</tr>
<tr>
<td><strong>Cleaning of SCR</strong></td>
<td>not available</td>
</tr>
<tr>
<td><strong>Cost per cleaning</strong></td>
<td>not available</td>
</tr>
<tr>
<td><strong>Average operational cost</strong></td>
<td>not available</td>
</tr>
</tbody>
</table>

Based on the information in the Table 2.2 and Table 2.3, we are able to estimate the investment (CAPEX) and operation costs (OPEX) for the SCR use in the Baltic shipping. To calculate the CAPEX and OPEX of SCR we have to create a future scenario which takes into account the fleet renewal and traffic growth. Tier III is valid for new ships.
(constructed on or after 1.1.2016) only and therefore the future scenarios are created until 2040 to provide sufficient time span for cost estimation.

The results from the SNOOP project are the base for the future scenario. The future scenario is built on the real Baltic ship traffic information which is based on the HELCOM AIS database. Therefore the fleet information includes the real ships that have visited in the Baltic Sea in 2008 which is the base year of the scenarios. The SNOOP project estimates the NOx emissions and fuel consumption for every individual ship in 2008 in the Baltic Sea.

2.3.1 Estimation of the investment costs, CAPEX

The CAPEX is estimated based on the future scenario of installed engine power (kW) in new ships (including both main and auxiliary power). It has been assumed for all 12 ship types that the lifetime of a ship is 30 years. After 30 years the ship is removed from the fleet and replaced with the same power amount as a new built ship complying the prevailing Tier standard. This means that Tier I is applied until 31.12.2010, Tier II until 31.12.2015 and when the scenario reaches 1.1.2016 all new ships are complying with the Tier III.

In the first estimated year (2009) all ships older than 30 years are replaced with the corresponding amount of new engine power. This means that the amount of replaced old engine power is high in the first year because all old ships are removed from the fleet. In 2010 engine power built only in one year, 1980, is replaced. This calculation method continues until 2040. When the scenario reaches the 2016 it has been assumed that renewed engine power will be fitted with the SCR. The traffic growth has been assumed to be 2 % in a year. The future scenario assumes that all traffic growth is new ships complying the standard valid in the current year. In other words in 2016 all traffic growth and ship renewal are assumed to have SCR.

Fleet renewal and traffic growth in the future scenarios are assumed to be new ships. This will lead to overestimation of the CAPEX and operation costs (OPEX) because in practice renewal and traffic growth could also include few years older ships (Tier I and Tier II ships) and therefore delaying the introduction of Tier III vessels. However, in the long run there will not be enough older fleet available and renewal as well as the traffic growth will be new ships. However, possible establishment of new NECA areas around the world will bind the world fleet forcing to invest in new ships for NECA traffic and faster introduction of Tier III ships. Future scenario calculations show the share of NOx emissions per Tier standard ships (Figure 3.2).

Wärtsilä estimates that the life time for a basic SCR construction can last as long as the ship. CAPEX scenarios assume that the SCR equipment will cost 50 €/kW and last 25 years. The expenditure is allocated through the SCR lifetime with annuity loan method
where interest rate will be a constant of 10 %, payment once per year (25) and residual value zero.

The raw data for the base year 2008 includes more than 6 000 ships from which a major part sails only few days in the Baltic. In practice, if a Baltic NECA will be established, there will be Tier III ships that are mainly sailing in the Baltic and the amount of ships that rarely visit the Baltic will be reduced. Therefore two different CAPEX scenarios are created. First one (scenario 1) assumes that all new engine power is fitted with SCR in 2016 and the other (scenario 2) assumes that the SCR is installed only on the share of engine power that represented 95 % of the NOx emissions of certain ship type in 2008. With this method it is possible to reduce considerable amount of SCR CAPEX and make the scenario more realistic.

The shares of engine power representing 95 % of the NOx emissions of each ship type are presented in the Table 2.4. For example, the general cargo (GC) ships produced 48.7 kilotonnes of NOx in the Baltic in 2008. Total engine power of the GC ships that visited the Baltic was 6,844 MW. GC ships that produced 95 % of the NOx emissions had total engine power of 4,517 MW which is 66 % of the total engine power of GC ships. This 66 % is used in the CAPEX scenarios on and after 2016 to calculate the share of engine power which is installed with SCR technology. In other words: in 2016, the sum of engine power of the 2 % traffic growth and renewal of the GC fleet will be multiplied with 0.66 and investment cost of 50 €/kW to produce CAPEX. However, this assumption might still lead to overestimation of the CAPEX. Nevertheless, it makes the CAPEX scenario much more reliable. OPEX estimation does not need similar assumption because it is depending on the fuel consumption, which is assumed to be the same in both scenarios.

It should be noted that there are a lot of ships in the Baltic that would operate both inside and outside of the Baltic NECA. If the NECA area would also cover for example the North Sea it would decrease the abatement cost estimations presented in this study.
Table 2.4 CAPEX scenario and estimation of engine power on which SCR will be installed.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>NOx emissions in 2008 (kilotonnes)</th>
<th>Installed total engine power (MW) (base for the scenario 1)</th>
<th>Share of engine power representing 95 % of the NOx emissions (base for the scenario 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reefer ship</td>
<td>7.8</td>
<td>3 248</td>
<td>68 %</td>
</tr>
<tr>
<td>2 General cargo ship</td>
<td>48.7</td>
<td>6 844</td>
<td>66 %</td>
</tr>
<tr>
<td>3 Product tanker</td>
<td>9.0</td>
<td>2 218</td>
<td>60 %</td>
</tr>
<tr>
<td>4 Container ship</td>
<td>36.3</td>
<td>6 442</td>
<td>30 %</td>
</tr>
<tr>
<td>5 Chemical tanker</td>
<td>33.0</td>
<td>6 635</td>
<td>60 %</td>
</tr>
<tr>
<td>6 Crude oil tanker</td>
<td>19.4</td>
<td>5 016</td>
<td>60 %</td>
</tr>
<tr>
<td>7 Bulk ship</td>
<td>18.2</td>
<td>8 242</td>
<td>70 %</td>
</tr>
<tr>
<td>8 Ro-ro ship</td>
<td>37.6</td>
<td>2 187</td>
<td>65 %</td>
</tr>
<tr>
<td>9 Ropax ship</td>
<td>107.9</td>
<td>4 211</td>
<td>75 %</td>
</tr>
<tr>
<td>10 Vehicle carrier</td>
<td>7.3</td>
<td>3 125</td>
<td>37 %</td>
</tr>
<tr>
<td>11 Liquid petroleum gas tanker</td>
<td>2.2</td>
<td>782</td>
<td>62 %</td>
</tr>
<tr>
<td>12 Cruise ship</td>
<td>5.6</td>
<td>2 367</td>
<td>70 %</td>
</tr>
</tbody>
</table>

2.3.2 Estimation of the operation costs, OPEX

Estimation of the SCR OPEX in this study is based on the fuel consumption of the Baltic fleet in 2008. Scenarios also assumes that if ship leaves the NECA it will shut down the SCR. Future scenario of the fuel consumption is created until 2040 including consumption from both main and auxiliary engines. OPEX scenario assumes a traffic growth of 2 % per year. Development of the fuel efficiency of the engines has not been included in the scenario calculations.

Operation costs of the SCR consist mainly of the urea consumption which depends on the rate of NOx emissions abatement efficiency. Wärtsilä estimates that urea consumption is about 10 % of the fuel consumption to achieve the Tier III level. In the future engines initial NOx emissions are expected to decrease and hence decreasing the operating costs of the SCR. Wärtsilä estimates that the urea costs are around 4–6 €/MWh and an average overall costs of the SCR are 5–7.5 €/MWh. In scenarios of this study it has been assumed that 80 % of the total operation costs are urea costs.

Wärtsilä estimates that the life time for a basic SCR construction can last as long as the ship. However, regular maintenance and replacement of components and catalyst elements in certain intervals must be done. Typical cost for the replacement of the catalyst
Elements is 0.25–0.75 €/MWh. The elements will be changed only when the activity level has reduced below determined level. In addition visual check and simultaneously manual cleaning if needed should be done once a year. The desired interval for element replacement depends on various factors like operation conditions, fuel type, element type and process control. Every rebuilding project is separate case and therefore the total OPEX in the scenarios is bound to the urea consumption to keep the calculation simple.

The OPEX assumes the price for the urea to be 150 €/tonne. This price is for urea solution of 40 weight-percent and delivered to the Stockholm area by Fred Holmberg & Co (2nd June 2010). We have no estimation for the future development of the urea price but the last changes in the price can be seen in the Figure 2.2 (for 100 wt % urea). It is clear that the price of urea is a sensitive factor for the operation costs due to the assumption that 80 % of the total operation costs are urea costs. The development of fuel prices during last years is shown in the Figure 2.3.

![Figure 2.2 Urea (100 wt %) price from June 2005 to May 2010.](source: www.crugroup.com)
Figure 2.3 Fuel prices in US$ per tonne. Source: Wärtsilä.

* IFO 380 - Intermediate fuel oil with a maximum viscosity of 380 Centistokes
* LS 380 - Low-sulphur (<1.5%) intermediate fuel oil with a maximum viscosity of 380 Centistokes
* MGO - Marine gasoil
* MDO - Marine diesel oil

2.4 Additional costs on freight rates

The estimations of the use of Tier III NOx emission reduction equipment on freight rates of new vessels are based on the results of the NECA additional costs for the Baltic shipping of this study combined with the data of a study on ship operating costs made by CMS for the Finnish Maritime Administration (Karvonen T. & T. Makkonen 2009). The estimation is very simplified because there is a vast amount of factors effecting to the freight rates.

The first basic assumption is that all other factors remain unchanged except these NOx-related factors. For example the presumable reduction of fuel consumption due to the technological development in ship engines or the high additional costs of the fuel switch to comply the MARPOL Annex VI in SECAs (see 2.3.2.) are not taken into account. The overall rising costs of building new ships are neither taken into account. This is reasoned by the aim to keep the estimation simple enough and to raise the NOx-factor clearly visible. The second assumption is that rising operating costs will be incorporated directly and fully into the freight rates. In reality there are many factors (e.g. market situation, customer differentiated rates etc.) effecting and dampening the rise of rates.
The calculations are based on the next default values:

1. To the investment cost of a new vessel 50 Euros per kW is added as the cost of installing SCR technology in the engines (both main and auxiliary). This is automatically calculated in annuity, capital costs, repairs and maintenance, insurance and over head costs.
2. The costs of the urea consumptions are added to the fuel costs so that the urea consumption is assumed to be 10% of the fuel consumption and the price for the urea 150 Euros per tonne.

2.5 Cost-effectiveness of nitrogen removal in other sectors

Nitrogen enters the Baltic Sea either as waterborne or airborne inputs. The average nitrogen load between 2000–2006 was approximately 650 kilotonnes. About 75% of the nitrogen entered the Baltic Sea as waterborne input and 25% as airborne input. Agriculture and managed forestry contributed almost 60% of the waterborne nitrogen inputs to the sea, 28% entered from natural background sources and 13% came from point sources. The airborne nitrogen input has been calculated as direct atmospheric deposition on the Baltic Sea. It originated from emissions to the air from inside as well as outside the Baltic Sea catchment area and from ship traffic. Nitrogen deposition from shipping in the Baltic Sea amounts to around 11,500 tonnes annually (average for 2000–2006) (Bartnicki J. & S. Valiyaveetil 2009) and to 12,400 tonnes in 2007 (Bartnicki et al. 2009).

As agriculture and municipal and industrial waste water are the most important sources of nitrogen, the cost-effectiveness of nitrogen removal from these sectors will be compared in relation to that in ship traffic.

The wastewater treatment and agricultural practices in the countries bordering the Baltic Sea differ considerably, which makes it challenging to get a general picture of the cost-effectiveness on nitrogen removal in these sectors. The data on cost efficiency of nitrogen removal is scarce, and limited to specific cases. One major problem is to get commensurate figures, as cost-efficiency has been estimated in various ways. The single large waste water treatment investment in St. Petersburg has been analyzed (Vodokanal 2006). There is also data on agriculture in Kalajoki, Finland (Väisänen 2008) and Odense, Denmark (Environment Centre Odense 2007). NEFCO has estimated the cost-efficiency of nitrogen removal in the Baltic (NEFCO 2007).

A comparison figure of nitrogen abatement costs of various sectors including shipping is shown in the results (Figure 3.6).
2.5.1 Nitrogen load removal from agriculture

In general, it is rather cost efficient to remove nitrogen from agriculture (HELCOM 2007). There are several techniques to decrease nutrient loading from agriculture. These include: livestock reductions, changes in spreading periods of manure, wetlands, riparian buffers and diminishing fertilization. Not all of them have costs that can be calculated, e.g. diminishing fertilization. Building wetlands and riparian buffers have costs that can be calculated. In a case study in Finland it has been calculated that building artificial wetlands will yield a cost of 1,000–2,000 €/tonne nitrogen and riparian buffers will yield a cost of 10,000–20,000 €/tonne nitrogen (Väisänen 2008). According to NEFCO removing nitrogen from agriculture costs 3,500 €/tonne, and this is of the same magnitude as those in Väisänen (2008). In Odense, Denmark it was calculated that basic actions to remove nitrogen from agriculture will cost 16.9 M€ and they will remove 330 tonnes nitrogen and 5 tonnes phosphorus yearly (Environment Centre Odense 2007). Additional measures are necessary to fulfill the demands of Water Framework Directive, and these have been calculated to be 12.6 M€/year that will remove more than 900 tonnes nitrogen. It is, however, difficult to compare these figures to the other ones presented here.

2.5.2 Waste water treatment

In principle, the most cost efficient way to remove nitrogen is to build a wastewater treatment plant (WWTP) to a densely populated area with no prior waste water treatment. As an example of this is the St. Petersburg area in which with international co-operation the WWTP has been built. For example, building the northwest WWTP in St. Petersburg had a unit cost of 5,000 €/tonne nitrogen. However, for future actions, there are very few such areas left in the Baltic Sea catchment area, an exception of this is the Kaliningrad area.

Building WWTPs in sparsely populated area is not cost-efficient, the unit costs are much higher, up to 28,000 €/tonne nitrogen (Kiirikki et al. 2003) and according to NEFCO 30,000 €/tonne nitrogen.

The average nitrogen removal efficiency of a WWTP is 40–50 % and with further costs this percentage can be increased, for instance City of Helsinki has chosen to remove nitrogen with 70 % efficiency. It has been calculated that increasing the nitrogen removal rates of Finnish coastal WWTP:s has approximately the same unit cost (i.e. 5,000 €/tonne) than building the northwest WWTP in St. Petersburg. (Finnish Environment Institute: http://www.ymparisto.fi/default.asp?contentid=41178&lan=FI).

2.6 Unintentional traffic shift

In this chapter the potential for unintentional traffic shift from sea to road that might be caused by increasing operational costs is estimated. The question whether the NOx emission regulations will lead to a modal shift away from sea is very complicated. The
same issue has been under analysis in various studies concerning the SOx regulations and impacts of SECA areas. The European Commission launched a number of studies to get a thorough estimation of the consequences of the amendment to MARPOL Annex VI. One of them concentrates on the possible negative consequences for short sea shipping and the risk of modal shift due to the increase in fuel price by 2015. The final report has not yet been published but some drafts have been available.

There are a lot of factors influencing the choice of a transport service such as cost, transit time, reliability, flexibility, frequency, security, nature of cargo, value of cargo, relationships and existing contracts with transport suppliers etc. For some cargo types the sea transport is the only reasonable choice. Dry and liquid bulk cargoes are good examples of these. The cargoes carried on ro-ro vessels in short sea shipping are more potential for modal shift. In theory, a truck can be transferred from one point to another either driving the whole way on a road or transported some part of the way on a vessel or on a train wagon. In some cases there are no real alternatives for sea transport for trucks and trailers either, for example between South Finland and Sweden or Sweden and the Baltic States or Finland and Estonia. In the Baltic Sea the possibility for a modal shift exists foremost in transports between Sweden and the Continental Europe, inside Sweden (i.e. no long sea transports directly from northern parts, instead first by road or rail to southern Sweden), between Finland and the Continent (i.e. instead of direct sea transport across the Baltic to routes via the Baltic States or Sweden) and between Russia and the Central Europe.

The study made by Entec\(^1\) compared some studies which had analyzed the possible effects of new SOx regulations (MARPOL Annex VI). The conclusion was that the revised regulations will lead to some shift away from short sea shipping to road and rail. However, the shift varies significantly between different routes and price projections so there is not a common model to estimate such a shift. According to the same report, in the SOx regulations case the shift was expected to be between 3–50 % in volume depending the routes and price scenarios.

The rise of freight rates of new vessels caused by the new NOx regulations will according to our estimations (see chapter 3.3) be in average from 2 to 5 % depending on vessel type. This rise is so low that the potential for modal shift caused solely by the NOx regulations will most probably be very small, in most cases non-existent.

2.7 Economic incentives

In this chapter the possibilities to use economic incentives to cover the additional costs of the use of Tier III NOx emission reduction equipment on new ships are investigated.

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\(^1\) Study to Review Assessments Undertaken of the Revised MARPOL Annex VI Regulations (2010).
Economic incentives, policy instruments and other market based instruments to promote NOx abatement are studied by Kågeson (2009) in the report “Market-based Instruments for NOx abatement in the Baltic Sea”. The methods presented in the report are:

1. Differentiated port and fairway dues
2. Norwegian NOx-tax and NOx fund
3. Green Award (Rotterdam)
4. A scheme for NOx differentiated en-route charging
5. A baseline-and-tradable-credit scheme
6. Emissions trading
7. New system of differentiated port dues
8. The Clean Shipping Project

In this report, we will investigate the topic in the Baltic Sea scope and try to find the most suitable and useful incentives to be used in the Baltic Sea.

In principle there are two main types of incentives which can be used: positive and negative ones. In this case the positive incentives could be reduction of fairway and/or port dues to the ships using NOx abatement technology. The negative incentives could be charges on NOx emissions.

First of all, we should decide what aim we are going to reach with the incentives. The new rules will apply on new vessels from 1.1.2016. It is doubtful if the incentives in fairway or port dues are attractive enough for a ship owner to order a newbuilding. So in practice the incentives could be most useful in order to make the ship owners to equip the existing vessels with NOx abatement technology. As the new rules apply only new vessels, there is a risk that the use of older vessels in the Baltic Sea will increase. Especially this is the case with vessels occasionally visiting the Baltic Sea but also with vessels in liner traffic, too. The incentives would have best influence on the liner traffic.

The question of positive or negative incentives remains. In Sweden a system of differentiated fairway and port dues based on NOx and SOx emissions has been in use for some years already although not in all ports. According to Kågeson, the positive incentives are too small to make ship owners to invest in advanced methods for NOx abatement. If the incentives were significantly raised the income of dues would decrease. It is very difficult to find a level where the incentives would have enough influence without decreasing the income too much. The Norwegian model which is a combination of a modest charge and generous grants appears to be a better incentive but this combination makes it a quite complicated system, too.

Negative incentives such as charges on NOx emissions from ship engines would probably have more effective influences than the positive ones. Charges according to the amount of emissions would be a clear incentive for the ship owners to make them equip their ships with NOx abatement technology. It would also be consistent with the polluter pays principle and it would not decrease the total income collected by fairway and/or port dues.
The establishment of an effective and working charge system is a little bit more complicated than a system based on reduction of fees of those vessels, which have the emission abatement equipment installed. First of all it should be a uniform system covering the whole Baltic Sea. If one of two neighbouring countries applies the charge system and the other one does not, there is a risk that transit traffic and possibly also some other traffic will be diverted to the ports of that country and the incentive will be useless and only harming the ports of the first country. A lot of international cooperation is needed in establishing of a workable system.

A NOx-differentiated en-route charge would according to Kågeson be relatively easy to design and to operate. In order to be widely accepted, the revenues of charges should be recycled to the industry. The proceeds could be used as grants for investment in advanced abatement technologies. Kågeson assumes that the combined effect of a grant and a reduced charge (as a result of reduced emissions) should be enough for frequent visitors to justify investment in SCR in engines with a remaining life of about ten years. The grant could be up to 50 % of the incremental cost, as higher subsidy would over-compensate some ship owners at the expense of others. A high grant may also lead to rising prices on technology. It is also obvious that a lot of money will be needed in the first years of implementation of the scheme. It would be ideal that there would be one common fund for the whole Baltic Sea jointly run by the coastal states. The overall efficiency would be improved if the scheme included also the ports of the North Sea.

Whatever type of incentive (if any) will be chosen it is very important that it is enforced in a large geographical area, at least in all ports in one country but rather the whole Baltic Sea. It is not desirable that ships choose a port in a neighbouring country just in order to avoid a charge on emissions in one country. From the environmental point it is not desirable either that positive incentives redirect sea transports to more distant ports and cause longer road transports.

### 2.8 Fairway fee discount HELCOM recommendation

HELCOM recommendation 28E/13 draws a principle for a method how HELCOM countries could give discount to fairway fees based on environmental efficiency of a vessel. There is a discount table for NOx emission differentiated discount. Basic idea is that if a vessel performs better than demanded in MARPOL it will get a discount from the fee. In this study we have made a future scenario calculation which raw data is the real ships sailing in the Baltic in 2008 and visiting in Finland. If we assume those ships to be new ships built after 1.1.2016 and having a fuel consumption estimated for them in 2008, we can calculate their SCR total cost per year and compare that to the discount they would have from Finnish fairway fee. Results are shown in the Table 3.3.
3 Results

3.1 Tier III additional costs for the Baltic shipping

Figure 3.1 shows the result of a future scenario for NOx emissions until 2040 if Baltic NECA will be established or not. The scenario calculation shows that if the NECA will be established the ship borne NOx will turn to decrease. Otherwise it will continue to increase.

Figure 3.1 NOx emissions of the presented 12 ship types until 2040 in case of Baltic NECA and Tier II only.

Figure 3.2 shows how the NOx emissions are estimated to divide between Tier I, Tier II and Tier III ships. The figure helps to understand the assumptions made in the calculations; for example after 1.1.2016 the amount of Tier II vessels is not increasing anymore and therefore their share of emissions will remain small in the scenario.
Figure 3.2 Division of NOx emissions between Tier I, II and III ships in the Baltic Sea until 2040.

Total additional cost of the Tier III is presented in the Figure 3.3. Scenario 1 shows a cost of 76.6 million Euros in 2020 and 289 million Euros in 2030. Scenario 2 shows costs of 55.6 and 206 million Euros respectively. Figure 3.3 also demonstrates the scale of operation costs compared to total costs (interest rate 10%).
NOx abatement costs per year until 2040, traffic increase 2%, vessel lifetime 30 years, 12 shiptypes

Figure 3.3 SCR cost estimation for Baltic shipping until 2040. Investment cost of 50 € per kW, SCR installed to engine power representing 100 % (scenario 1) and 95 % (scenario 2) of NOx emissions in 2008. Interest rate 10%.

Total additional cost of the Tier III, with interest rate of 5%, is presented in the Figure 3.4. Scenario 1 shows a cost of 56.9 million Euros in 2020 and 213 million Euros in 2030. Scenario 2 shows costs of 43.4 and 160 million Euros respectively.
Figure 3.4 Same as Figure 3.3 except with interest rate of 5%.

In Figure 3.5 is presented the cost per abated tonne of NOx. An average cost for scenario 1 is 1,844 Euros per tonne and 1,316 Euros per tonne for the scenario 2. The cost of scenarios 1 and 2 is converted to elemental nitrogen (multiplied by 3.286) and then the average costs are 6,059 and 4,326 Euros per tonne respectively. The abatement cost varies between ship types from 787 (ropax, Table 3.1, Figure 3.7) to 3,415 (bulk) Euros per tonne of NOx (scenario 2). In Table 3.2 are the same calculations but the interest rate is changed from 10% to 5%.

Table 3.1 NOx abatement costs of each ship type, sorted according the scenario 2. Interest rate 10%.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Scenario 1 [€/tonne NOx]</th>
<th>Scenario 1 [€/tonne N]</th>
<th>Scenario 2 [€/tonne NOx]</th>
<th>Scenario 2 [€/tonne N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROPAX</td>
<td>873</td>
<td>2 869</td>
<td>787</td>
<td>2 585</td>
</tr>
<tr>
<td>RO-RO</td>
<td>1 083</td>
<td>3 558</td>
<td>890</td>
<td>2 923</td>
</tr>
<tr>
<td>Container ships</td>
<td>1 988</td>
<td>6 534</td>
<td>919</td>
<td>3 021</td>
</tr>
<tr>
<td>General cargo</td>
<td>1 724</td>
<td>5 665</td>
<td>1 305</td>
<td>4 290</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>2 319</td>
<td>7 619</td>
<td>1 572</td>
<td>5 167</td>
</tr>
<tr>
<td>Product tankers</td>
<td>2 542</td>
<td>8 354</td>
<td>1 706</td>
<td>5 605</td>
</tr>
<tr>
<td>Vehicle carriers</td>
<td>4 698</td>
<td>15 439</td>
<td>2 009</td>
<td>6 600</td>
</tr>
<tr>
<td>Crude oil tankers</td>
<td>3 161</td>
<td>10 387</td>
<td>2 056</td>
<td>6 757</td>
</tr>
<tr>
<td>Liquid Petroleum Gas Tanker</td>
<td>4 044</td>
<td>13 289</td>
<td>2 673</td>
<td>8 783</td>
</tr>
<tr>
<td>Cruise ships</td>
<td>4 339</td>
<td>14 257</td>
<td>3 166</td>
<td>10 403</td>
</tr>
<tr>
<td>Reefer ships</td>
<td>4 663</td>
<td>15 322</td>
<td>3 311</td>
<td>10 881</td>
</tr>
<tr>
<td>Bulk ship</td>
<td>4 699</td>
<td>15 440</td>
<td>3 415</td>
<td>11 223</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>1 844</td>
<td>6 059</td>
<td>1 316</td>
<td>4 326</td>
</tr>
</tbody>
</table>

Table 3.2 NOx abatement costs of each ship type, sorted according the scenario 2. Interest rate 5%.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Scenario 1 [€/tonne NOx]</th>
<th>Scenario 1 [€/tonne N]</th>
<th>Scenario 2 [€/tonne NOx]</th>
<th>Scenario 2 [€/tonne N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROPAX</td>
<td>750</td>
<td>2 465</td>
<td>695</td>
<td>2 283</td>
</tr>
<tr>
<td>Container ships</td>
<td>1 445</td>
<td>4 748</td>
<td>756</td>
<td>2 485</td>
</tr>
<tr>
<td>RO-RO</td>
<td>886</td>
<td>2 913</td>
<td>762</td>
<td>2 504</td>
</tr>
<tr>
<td>General cargo</td>
<td>1 286</td>
<td>4 225</td>
<td>1 016</td>
<td>3 340</td>
</tr>
<tr>
<td>Chemical tankers</td>
<td>1 655</td>
<td>5 437</td>
<td>1 174</td>
<td>3 858</td>
</tr>
<tr>
<td>Product tankers</td>
<td>1 798</td>
<td>5 908</td>
<td>1 259</td>
<td>4 137</td>
</tr>
<tr>
<td>Vehicle carriers</td>
<td>3 197</td>
<td>10 504</td>
<td>1 464</td>
<td>4 812</td>
</tr>
<tr>
<td>Crude oil tankers</td>
<td>2 178</td>
<td>7 157</td>
<td>1 466</td>
<td>4 819</td>
</tr>
<tr>
<td>Liquid Petroleum Gas Tanker</td>
<td>2 759</td>
<td>9 068</td>
<td>1 876</td>
<td>6 165</td>
</tr>
<tr>
<td>Cruise ships</td>
<td>2 947</td>
<td>9 685</td>
<td>2 192</td>
<td>7 203</td>
</tr>
<tr>
<td>Reefer ships</td>
<td>3 159</td>
<td>10 382</td>
<td>2 289</td>
<td>7 521</td>
</tr>
<tr>
<td>Bulk ship</td>
<td>3 176</td>
<td>10 436</td>
<td>2 349</td>
<td>7 720</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>1 363</td>
<td>4 477</td>
<td>1 023</td>
<td>3 361</td>
</tr>
</tbody>
</table>
Factors affecting most to the abatement costs are the investment cost per kW (50 €/kW in this study), the amount of NOx emissions and fuel consumption of a ship in the Baltic Sea area and the share of engine power the SCR is assumed to be installed (engine power covering 95% of the NOx emissions in 2008, scenario 2). Naturally also the traffic increase and fleet renewal are sensitive factors in the scenario calculations. The interest rate for the investment of the SCR also presents a major effect. In Figure 3.4 Figure 3.6 and Figure 3.8 and Table 3.2 are the same results with 5% interest rate.

Figure 3.5 An average cost per abated tonne of NOx for Baltic shipping (scenario 1 and 2). An average cost per abated tonne of N for Baltic shipping (scenario 2). Interest rate 10%.
Figure 3.6 Same as Figure 3.5 except with 5% interest rate.

Figure 3.7 Costs per abated tonne of NOx for RoPax ships. Interest rate 10%.
RoPax ships - Costs per abated ton of NOx, scenario1 and 2

Cost [€ per abated ton NOx]
Cost per abated ton of NOx (scenario 2)
Cost per abated ton of NOx (scenario 1)

Figure 3.8 Same as Figure 3.7 except with 5% interest rate.

In the Figure 3.6 is shown a comparison of average costs of nitrogen abatement in various sectors, which are agriculture, waste water treatment and shipping. All nitrogen from ships is not deposited onto the sea. It is estimated that about ten per cent of ship originated nitrogen is deposited directly onto the sea. In that case the costs of removing nitrogen from shipping should be multiplied with 10 (see conclusions).

Figure 3.9 Comparison of average nitrogen abatement costs in various sectors (costs per abated tonne of N). The costs of removing N from shipping do not take into account how much of the total N from shipping will be deposited onto the Baltic Sea. (WWTP = building a waste water treatment plant)
3.2 Economic incentives to compensate the SCR costs

In the Table 3.3 are shown 24 ships and their details used in calculation of a fairway fee when visiting in Finland. Ship data is based on actual ships with estimated fuel consumption in 2008. If Finland would have rationalized the HELCOM recommendation 28E/13 it would give a discount to ships based on their emissions below the prevailing MARPOL Annex VI level. If we assume that the level on which current emissions of the ship are compared would be Tier II and a ship has an operational SCR in all engines with abatement efficiency of 80 % the ship would have the following tabulated discount on fairway fees. The discount in some cases will be significant when comparing the annual total cost of the SCR.
Table 3.3 Ships having a discount from the fairway fee in Finland, future scenario.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>GRT</th>
<th>Net tonnage</th>
<th>Port calls to Finland</th>
<th>fairway fee per year [€]</th>
<th>Tier I emission level [g/kWh]</th>
<th>Tier III emission level [g/kWh]</th>
<th>Emission differential [g/kWh]</th>
<th>HELCOM 28E/13 Discount €/netto</th>
<th>Discount %</th>
<th>Discount €/year</th>
<th>Fuel consumption 2008 [tonnes]</th>
<th>TOT power [kW]</th>
<th>SCR Operation costs [€]</th>
<th>SCR Investment costs per year [€]</th>
<th>tot SCR cost per year [€]</th>
<th>Discount [%] from annual SCR cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>roro</td>
<td>12460</td>
<td>3738</td>
<td>10</td>
<td>82 909</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.200</td>
<td>7 476</td>
<td>9</td>
<td>12.46</td>
<td>11 700</td>
<td>83 493</td>
<td>64 448</td>
<td>147 941</td>
<td>5</td>
</tr>
<tr>
<td>roro</td>
<td>6620</td>
<td>1986</td>
<td>10</td>
<td>23 534</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.200</td>
<td>3 972</td>
<td>17</td>
<td>6.62</td>
<td>5 611</td>
<td>43 398</td>
<td>30 908</td>
<td>74 305</td>
<td>5</td>
</tr>
<tr>
<td>RoPax</td>
<td>34728</td>
<td>18745</td>
<td>30</td>
<td>448 755</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.174</td>
<td>97 849</td>
<td>22</td>
<td>34.73</td>
<td>34 428</td>
<td>202 650</td>
<td>189 643</td>
<td>392 293</td>
<td>25</td>
</tr>
<tr>
<td>roro</td>
<td>6620</td>
<td>1986</td>
<td>10</td>
<td>23 534</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.200</td>
<td>3 972</td>
<td>17</td>
<td>6.62</td>
<td>5 756</td>
<td>46 699</td>
<td>31 706</td>
<td>78 406</td>
<td>5</td>
</tr>
<tr>
<td>roro</td>
<td>6620</td>
<td>1986</td>
<td>10</td>
<td>23 534</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.200</td>
<td>3 972</td>
<td>17</td>
<td>6.62</td>
<td>7 136</td>
<td>55 379</td>
<td>39 308</td>
<td>94 687</td>
<td>4</td>
</tr>
<tr>
<td>roro</td>
<td>12460</td>
<td>3738</td>
<td>10</td>
<td>82 909</td>
<td>14.50</td>
<td>2.90</td>
<td>8.70</td>
<td>0.200</td>
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Additional cost of Tier III to freight rates

For background information, using the 50 €/kW investment cost on main and auxiliary engines means a rise of 1–3 % in the total price of a new vessel depending ship type and size according to the given data in the study. The rise of fuel costs is 5.5 % using the given urea consumption and price. Total ship operating costs (per TEU or tonne per sea day) would rise as shown in the Table 3.3 and in this study it is assumed that the rise of total costs will be incorporated in the same relation into the sea freight rates.

The estimation is done in three ship size categories for five ship types. The figures presented in the Table 3.3 are average percentage values for estimated rise in freight rates of new vessels. There may be a variation of some decimals in the values in each category. The bigger estimated rise in the rates of large container vessels is mainly caused by the big average engine power (kW) of large ocean vessels with very high maximum service speed. It is somewhat irrelevant in the case of the Baltic Sea as the biggest container vessels are not used or even are not able to be used in these waters (partly because the volumes of containerized cargo in the Baltic Sea are too small for these giant vessels and partly because the vessels are too large for port infrastructure in the area).

Table 3.4 Estimated percentage rise in freight rates of new vessels due to the use of Tier III NOx emission reduction equipment.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Size category Small</th>
<th>Size category Medium</th>
<th>Size category Large</th>
</tr>
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<tr>
<td>Container vessel</td>
<td>2.8 %</td>
<td>4.2 %</td>
<td>4.6 %</td>
</tr>
<tr>
<td>General dry cargo vessel</td>
<td>2.4 %</td>
<td>3.6 %</td>
<td>3.7 %</td>
</tr>
<tr>
<td>Dry bulk vessel</td>
<td>3.4 %</td>
<td>3.3 %</td>
<td>3.2 %</td>
</tr>
<tr>
<td>Oil tanker</td>
<td>2.0 %</td>
<td>3.1 %</td>
<td>3.4 %</td>
</tr>
<tr>
<td>Ro-ro and ropax vessel</td>
<td>3.1 %</td>
<td>3.3 %</td>
<td>3.4 %</td>
</tr>
</tbody>
</table>

Size categories:

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Size category Small</th>
<th>Size category Medium</th>
<th>Size category Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container vessel</td>
<td>&lt; 1,000 TEU</td>
<td>1,000 - 3,500 TEU</td>
<td>&gt; 3,500 TEU</td>
</tr>
<tr>
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<td>&lt; 6,000 dwt</td>
<td>6,000 - 18,000 dwt</td>
<td>&gt; 18,000 dwt</td>
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<tr>
<td>Dry bulk vessel</td>
<td>&lt; 30,000 dwt</td>
<td>30,000 - 60,000 dwt</td>
<td>&gt; 60,000 dwt</td>
</tr>
<tr>
<td>Oil tanker</td>
<td>&lt; 20,000 dwt</td>
<td>20,000 - 60,000 dwt</td>
<td>&gt; 60,000 dwt</td>
</tr>
<tr>
<td>Ro-ro and ropax vessel</td>
<td>&lt; 5,000 dwt</td>
<td>5,000 - 10,000 dwt</td>
<td>&gt; 10,000 dwt</td>
</tr>
</tbody>
</table>
4 Discussion and conclusions

The abated nitrogen from maritime traffic is approximately as cost efficient when compared to agriculture and waste water treatment. Abating nitrogen from especially the ro-ro, ropax and container vessels are cost efficient, the unit costs may be below 3,000 €/tonne of nitrogen. Short sea shipping is a special characteristic of the Baltic shipping and these few ro-ro, ropax and container vessels consume a high amount of bunker fuel in the area. Abatement costs would decrease (and cost efficiency would increase) if more NECA areas near the Baltic Sea would be established and if ships that have an SCR will use it even if they are not in the NECA area. For example North Sea NECA would lead to increased amount of SCR operation time of individual ships sailing both in and outside of the Baltic.

The selective catalytic reduction (SCR) is the only technology today which meets the Tier III reduction requirements and from which we know enough to make cost estimates. Cost calculations show that with 10% interest rate for the SCR investment, abatement of one tonne of NOx will cost 787–4,699 Euros (2,585–15,440 Euros per abated tonne of nitrogen) depending on the type of a ship and the method of calculation. However, the average cost is about 1,316–1,843 Euros per tonne NOx (4,325–6,059 Euros per tonne of nitrogen). With 5% interest rate the abatement costs will decrease to 695–3,176 Euros (2,283–10,436 Euros per abated tonne of nitrogen) and the average cost 1,022–1,362 Euros per tonne NOx (3,360–4,476 Euros per tonne of nitrogen) respectively.

Comparison with the cost efficiency of nitrogen abatement from the shipping to other sectors is difficult due to the fact that the estimation of deposition of NOx onto the Baltic Sea is challenging. It is equally challenging to estimate how much of the waterborne nitrogen from differing sources enters the Baltic Sea, and in fact such estimates do not exist. It is, however, known that major part of the nitrogen from inland sources will be retained or denitrified and does not enter the Baltic Sea. Modelling of the NOx deposition from shipping is not possible alone because the background emissions from other sources affect to the atmospheric chemistry and the amount of total NOx deposition.

It has been estimated that the total deposition of nitrogen to the Baltic Sea in 2007 was 202 kilotonnes (Bartnicki 2010). Bartnicki also estimates that 12.4 kilotonnes of nitrogen deposition originates from the shipping. Jalkanen (2009) states that the NOx emissions of Baltic shipping were 400 kilotonnes. If we convert the 400 kilotonnes of NOx to nitrogen we get 121.7 kilotonnes. This leads to an estimation of (12.4/121.7 = 0.1) 10 % of the total nitrogen from shipping will be deposited onto the Baltic Sea. If we apply this assumption to the cost figures presented in this study we have to multiply the costs with 10. This would give an average abatement cost per tonne nitrogen for scenario 1: 60,590 Euros and scenario 2: 43,255 Euros. These figures would be the ones to compare with the figures from other sectors for example waste water treatment plants whose abatement cost figures are estimated for nitrogen discharged directly to the sea. However, we should remember that cost figures presented for NOx abatement also include the health aspect as
improved air quality. All this is comparison of abatement costs; the cost efficiency between the sectors is a different task and cannot be done within this study.

We should also bear in mind that the catchment area of the Baltic Sea is vast and part of the deposited NOx of shipping outside the Baltic Sea will eventually wash into the sea. One important factor contributing to the harmfulness of the nitrogen to the Baltic Sea ecosystem is the time of the year when nitrogen enters the Baltic Sea. It is known that nutrients entering the Baltic Sea after the spring bloom (i.e. during summer) are the most harmful, as they feed the cyanobacterial blooms. However, most of the cyanobacteria are nitrogen-fixers and thus not limited by nitrogen. For both shipping and other sectors, the seasonal variation is high, but for shipping especially high deposition happens in the summer period. This means that the environmental impact of one tonne of nitrogen varies between the sectors and the comparison of abatement cost figures is difficult.

Designation of the Baltic Sea as a NECA would increase the freight rates of shipping. Estimations show that due to use of Tier III NOx emission reduction equipment (SCR) an increase of 2–4.6 % in freight rates of new ships depending on vessel type is possible. The highest rise of costs will be on large and fast container vessels. These estimations are made on the basic assumption that only those costs which are affected by new NOx regulations are taken into account.

It is probable that revised regulations will lead to some shift away from short sea shipping to road and rail. However, the shift varies significantly between different routes and price projections. The potential for modal shift caused solely by the NOx regulations will most probably be very small, in most cases non-existent.

The use of economic incentives to compensate the additional costs of the use of Tier III NOx emission reduction equipment on new ships for the shipowners is in principle a good idea but there are some problems in different types of incentives. The positive ones, such as reductions on fairway fees, may not be enough effective without losing too much on the income side. However, case calculation for the implementation of HELCOM recommendation 28E/13 in Finnish fairway fee system shows that some ships with frequent port calls to Finland would get a significant economic incentive. Internalizing this recommendation to fairway fee system of the HELCOM countries could give significant compensations extending to even 45 % of the annual additional costs of the use of SCR. If the NOx differentiated fairway fee system would be in common use in the Baltic the cumulative effect could be strong enough to increase SCR investments.

The negative ones, such as charges on emissions, require a cost efficient system of collecting and monitoring. A combination of reductions and charges might be an effective scheme. The industry should benefit from the incentives so that it would be economically lucrative to invest in emission abatement equipment on existing vessels, too. It is also very important that the incentives are enforced in a large geographical area, at least in all ports in one country but rather the whole Baltic Sea. It is not desirable that ships choose a port in a neighbouring country just in order to avoid a charge on emissions in one country.
References


Consequences of the IMO’s new marine fuel sulphur regulations 2009. Swedish Maritime Administration.


protection in the Gulf of Finland – Focus on St. Petersburg. The Finnish Environmental Institute 632.

Kågeson P. 2009. Market-based instruments for NOx abatement in the Baltic Sea. Air pollution and climate series 24. Published in October 2009 by the Air Pollution & Climate Secretariat (AirClim), the European Environmental Bureau (EEB) and the European Federation for Transport and Environment (T&E)


**Interviews**

Hellen, Göran (Senior manager, engine@regulatory affairs, Wärtsilä Oyj). Personal interview 12.5.2010.
Appendix 1

Figure 0.1 BULK, development of the cost per abated tonne of NOx.

Figure 0.2 GC, development of the cost per abated tonne of NOx.
RoPax ships - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.3 ROPAX, development of the cost per abated tonne of NOx.

RoRo ships - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.4 RORO, development of the cost per abated tonne of NOx.
Liquid petroleum tankers - Costs per abated ton of NOx, scenario1 and 2

Cruiser ships - Costs per abated ton of NOx, scenario1 and 2

Figure 0.5 T_LPG, development of the cost per abated tonne of NOx.

Figure 0.6 PAS_CR, development of the cost per abated tonne of NOx.
Crude oil tankers - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.7 T_CRD, development of the cost per abated tonne of NOx.

Container ships - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.8 CONT, development of the cost per abated tonne of NOx.
Figures 0.9 RC, development of the cost per abated tonne of NOx.

Figures 0.10 T_CHEM, development of the cost per abated tonne of NOx.
Vehicle carriers - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.11 V, development of the cost per abated tonne of NOx.

Product tankers - Costs per abated ton of NOx, scenario 1 and 2

Figure 0.12 T_PROD, development of the cost per abated tonne of NOx.
Appendix 2

Tier I
Tier I applies to marine diesel engine installed on a ship constructed on or after 1 January 2000 and prior to 1 January 2011. The emission requirements are set at the same level as current requirements:

a) 17.0 g/kWh when n (rated engine speed) is less than 130 rpm
b) 45·n^{(0.2)} g/kWh when n is 130 or more but less than 2000 rpm
c) 9.8 g/kWh when n is 2000 rpm or more.

Tier II
Tier II applies to marine diesel engine installed on a ship constructed on or after 1 January 2011:

a) 14.40 g/kWh when n is less than 130 rpm
b) 44·n^{(0.23)} g/kWh when n is 130 or more but less than 2000 rpm
c) 7.7 g/kWh when n is 2000 rpm or more.

Approximately a 15% reduction level will be achieved comparing to the current legislation and tier I.

Tier III
Tier III applies to marine diesel engine installed on a ship constructed on or after 1 January 2016, subject to some exemptions, operating in an Emission Control Area:

a) 3.4 g/kWh when n is less than 130 rpm
b) 9·n^{(0.2)} g/kWh when n is 130 or more but less than 2000 rpm
c) 2.0 g/kWh when n is 2000 rpm or more.

An Emission Control Area is to be designated according to the approved criteria and procedures.

80 % reduction will be achieved in ECAs comparing to the current legislation and tier I.

Pre-2000 ships
Marine diesel engines installed on a ship constructed on or after 1 January 1990 and prior to 1 January 2000, subject to some specific limitations, will be required to meet the emission standard of current Annex VI (see Tier I).

The revised Annex VI will enter into force on 1 July 2010. All HELCOM Contracting Parties but one have ratified the Annex.