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EXTERNALITIES OF SHIPPING IN THE GULF OF FINLAND UNTIL 2015

Juha Kalli & Ulla Tapaninen

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FOREWORDS

Maritime traffic in the Gulf of Finland has grown remarkably during the 2000's, which is mainly due to the good economic development and the increasing oil production and transportation activities of Russia. The growth of maritime traffic is expected to continue in the Gulf of Finland in the future as well. Of the various effects shipping has on the environment, emissions to air are the focus of this study. Air emissions originating from ships are generally formed by diesel engines and by burning of fossil fuels.

During the last few years, the discussion on marginal social costs of transportation has been active. Applying the externalities as a tool to control transport would fulfil the polluter pays principle and simultaneously create a fair control method between transport modes. Several studies and new methods have been carried out to minimize these costs but so far implementing the new policies has been quite limited. This report presents a method to calculate the marginal social costs based on the externalities of air pollution from shipping in the Gulf of Finland.

The research report was done as a part of the research project "SAFGOF - Evaluation of the traffic increase in the Gulf of Finland during the years 2007-2015 and the effect of the increase on the environment and traffic chain activities". This report is the result of the work package 4 "Traffic growth and ship originated atmospheric emissions" and the study has been performed by the Centre for Maritime Studies in the University of Turku. The project is financed by the European Union, the city of Kotka, Cursor – Kotka Hamina Regional Development Company, Port of Hamina, Finstaship, Koneteknologiakeskus Turku Ltd. and Kotka Maritime Research Centre.

The Centre for Maritime Studies in the University of Turku expresses its gratitude to all the researchers and other parties who have contributed to the collection of data, its analysis and to the writing of the results.

Turku 1st December, 2008

Juhani Vainio
Director
Centre for Maritime Studies

SUMMARY

During the last few years, the discussion on the marginal social costs of transportation has been active. Applying the externalities as a tool to control transport would fulfil the polluter pays principle and simultaneously create a fair control method between the transport modes. This report presents the results of two calculation algorithms developed to estimate the marginal social costs based on the externalities of air pollution. The first algorithm calculates the future scenarios of sea transport traffic externalities until 2015 in the Gulf of Finland. The second algorithm calculates the externalities of Russian passenger car transit traffic via Finland by taking into account both sea and road transport.

The algorithm estimates the ship-originated emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur oxides (SO_x), particulates (PM) and the externalities for each year from 2007 to 2015. The total NO_x emissions in the Gulf of Finland from the six ship types were almost 75.7 kilotons (Table 5.2) in 2007. The ship types are: passenger (including cruisers and ROPAX vessels), tanker, general cargo, Ro-Ro, container and bulk vessels. Due to the increase of traffic, the estimation for NO_x emissions for 2015 is 112 kilotons. The NO_x emission estimation for the whole Baltic Sea shipping is 370 kilotons in 2006 (Stipa & al, 2007).

The total marginal social costs due to ship-originated CO_2, NO_x, SO_x and PM emissions in the GOF were calculated to almost 175 million Euros in 2007. The costs will increase to nearly 214 million Euros in 2015 due to the traffic growth. The major part of the externalities is due to CO_2 emissions. If we neglect the CO_2 emissions by extracting the CO_2 externalities from the results, we get the total externalities of 57 million Euros in 2007. After eight years (2015), the externalities would be 28 % lower, 41 million Euros (Table 8.1). This is the result of the sulphur emissions reducing regulation of marine fuels.

The majority of the new car transit goes through Finland to Russia due to the lack of port capacity in Russia. The amount of cars was 339 620 vehicles (Statistics of Finnish Customs 2008) in 2005. The externalities are calculated for the transportation of passenger vehicles as follows: by ship to a Finnish port and, after that, by trucks to the Russian border checkpoint. The externalities are between 2 – 3 million Euros (year 2000 cost level) for each route. The ports included in the calculations are Hamina, Hanko, Kotka and Turku.

With the Euro-3 standard trucks, the port of Hanko would be the best choice to transport the vehicles. This is because of lower emissions by new trucks and the saved transport distance of a ship. If the trucks are more polluting Euro 1 level trucks, the port of Kotka would be the best choice. This indicates that the truck emissions have a considerable effect on the externalities and that the transportation of light cargo, such as passenger cars by ship, produces considerably high emission externalities.

The emission externalities approach offers a new insight for valuing the multiple traffic modes. However, the calculation of the marginal social costs based on the air emission externalities should not be regarded as a ready-made calculation system. The system is clearly in the need of some improvement but it can already be considered as a potential tool for political decision making.

Key words: marginal social costs, emission externalities, atmospheric emissions, Gulf of Finland, passenger car transit, truck, ship, transit traffic

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1 INTRODUCTION

Maritime traffic in the Gulf of Finland has grown remarkably during the 2000's. This is mainly due to the good economic development and the increasing oil production and transportation activities of Russia. It is widely expected that the growth of maritime traffic will continue in the Gulf of Finland also in the future (Kuronen & al, 2008).

Shipping has various effects on the environment of which emissions to air are the focus of this study. The ship-originated air emissions are generally formed by diesel engines and burning of fossil fuels. The increase of traffic in the Gulf of Finland creates an impact and a risk for the environment. These problems should be controlled to guarantee sustainable development and the welfare of inhabitants in the area.

During the last few years, the discussion on marginal social costs of transportation has been active. One method to estimate the impact of ship-originated air emissions to the environment is to calculate their environmental externalities (Bickel & al, 2006). These externalities are a part of the total marginal social costs of sea transport. Applying the externalities would fulfil the polluter pays principle and work as a fair traffic control method between the transport modes. (CEC, 1995).

Several studies and new methods have been carried out to minimize these costs but so far implementing the new policies has been quite limited. This report presents a system to calculate the marginal social costs based on the externalities of air pollution of shipping in the Gulf of Finland. Ship-originated CO_2, NO_x, SO_x and PM emission estimates are converted to externalities. The focus lies on six major ship types representing almost 90 % of the total emissions. The results and the traffic growth estimates from year 2007 have been taken into account in the development of the future scenarios until the year 2015.

The other part of this study consists of a calculation of emission externalities for the Russian passenger car transit traffic via Finland. We use the calculation algorithm to recognize the most sensitive variables affecting the externalities. The results will answer to the question whether such traffic should be concentrated on the ports near the Russian border instead of the ports traditionally considered as the main car import ports in Finland.

In this study report, we study the feasibility of marginal social cost approach to help the decision making between the modes of transport. We also study how the externalities as a method could help routing the traffic so that its external costs would be minimal. The scenarios present the impact of increasing sea transport on the environment in the form of externalities from 2007 to 2015. The scenario modelling is a method to estimate the effect of regulations and it helps to target the actions to maximize the profit. However, this report presents equally the limitations of such calculation systems.

The emission externalities approach offers a new insight for valuing the multiple traffic modes. However, the calculation of the marginal social costs based on air emission externalities should not be regarded as a ready-made calculation system. The system is clearly in the need of some improvement but it can already be considered as a potential tool for political decision making.

The research report has been done as a part of the research project "SAFGOF - Evaluation of the traffic increase in the Gulf of Finland During the years 2007-2015 and the effect of the increase on the environment and traffic chain activities". The project has begun on 1 January 2008 and it ends on 31 December 2010. This report is the result of the work package 4 "Traffic growth and ship originated atmospheric emissions" and the study has been performed by the Centre for Maritime Studies in the University of Turku. The project is financed by the European Union, European regional development fund, Regional Council of Kymenlaakso, City of Kotka, Kotka-Hamina regional development company Cursor Ltd., Kotka Maritime Research Association Merikotka, Kotka Maritime Research Center Corporate Group.

Centre for Maritime Studies is a special unit of the University of Turku and it is one of the leading providers of education, research and expert services in the maritime field in Finland. In addition to its national activities, the CMS has taken part in numerous international projects, especially concerning the area of the Baltic Sea. The Kotka office of the Centre for Maritime Studies works as a part of Kotka Maritime Research Centre. KMRC was established in 2005 and with it operates research units from four universities: University of Helsinki, Helsinki University of Technology, University of Turku and Kymenlaakso University of Applied Sciences.

This report has been formulated by Project Engineer Juha Kalli and Professor Ulla Tapaninen (University of Turku).

1.1 Results and conclusions

In this study, the total NO_x emissions are estimated to be almost 75.7 kilotons (Table 5.2) in 2007 in the Gulf of Finland. This is about 20 % of the total shipborne NO_x emissions in the Baltic Sea (370 kilotons in 2006, in BSR, Stipa & al, 2007). The results of this study include six major ship types: passenger (including cruisers and ROPAX vessels), tanker, general cargo, Ro-Ro, container and bulk vessels which are estimated to represent almost 90 % of the total emissions. Due to the increase of traffic, the estimation of the NO_x emissions for 2015 is 112 kilotons, which is almost 22 % of the estimated total Baltic Sea NO_x emissions.

The total cost of the ship-originated CO_2, NO_x, SO_x and PM emissions in the GOF was almost 175 million Euros in 2007. The costs will increase in the future, due to the traffic growth, to nearly 214 million Euros in 2015. The major part of the externalities is produced by the CO_2 emissions. If we extract the CO_2 externalities from the results, we get the total externalities of 57 million Euros in 2007. After eight years (2015), the externalities would be 28 % lower, 41 million Euros (Table 8.1). This is a result of the sulphur emissions reducing regulation of the marine fuels. Costs represented in this study are in the cost level of the year 2000.

The majority of the new car transit goes through Finland to Russia due to the lack of port capacity in the Russia. The amount of the cars is 339 620 vehicles in 2005 (Statistics of Finnish Customs, 2008). The second algorithm developed in this study estimates the externalities for the transportation of cars as follows: by a ship to a Finnish port and further on by a truck to the Russian border checkpoint. Air pollution externalities are 2 – 3 million Euros per year (year 2000 cost level) for each route (including the climate change externalities). The ports included in the calculations are Hamina, Hanko, Kotka and Turku.

With the Euro-3 classified trucks, the port of Hanko would be the best choice via which to transport the vehicles. This is because of lower emissions by the new trucks and saved transport distance of a ship. If the trucks are more polluting Euro 1 level trucks, the port of Kotka would be the best choice. This indicates that the truckborne emissions have a considerable effect on the externalities and that the transportation of light cargo as passenger cars by ship produce relatively plenty of emissions.

Several examples of marginal social costs are used as a tool for decision making. In Finland they are used when making the cost benefit estimations of new public roads or fairways. In Switzerland all heavy-duty vehicles, on all roads, have to pay charges from every transported kilometre based on the external costs. This report shows with the results of two calculation algorithms that the externalities can be used as a consultative tool in the transport decision making.

2 ENVIRONMENTAL IMPACT OF TRAFFIC GROWTH IN GOF

The Gulf of Finland is the most eastern part of the Baltic Sea, and its coastal states are Finland, Estonia and Russia. The Gulf of Finland is a shallow sea and the environmental conditions of the GOF are similar to those of the whole Baltic Sea. Thus, the species of the GOF are relatively exiguous by number but some of the species are exceptional. This makes the GOF ecosystem very sensitive to any disturbing factors.

The development of the maritime transportation in the Gulf of Finland is highly influenced by the situation in Russia (Kuronen & al, 2008). In the estimates, the slow growth scenario presents the total tonnes for the maritime transportation in the Gulf of Finland to grow to 322.4 M tonnes in 2015, which would mean the growth of 23 % compared to 2007. In the strong growth scenario, the growth could be 90 %. It should be noted that the traffic increase is not linearly dependent on the amount of the transported tons of cargo. This has been taken into account in this study when estimating the percentile growth of the ship type specific traffic.

Such growth of the transported cargo means a high rate of traffic increase in the future. Further on, increasing traffic leads to an increase of pollution. Already, the ship-originated atmospheric emissions are estimated to represent 50 % of the total deposition of the atmospheric NO_x in some seasons and areas in the Baltic Sea (Stipa & al, 2007). Thus, the ship-originated NO_x can be considered as a significant contributor to the eutrophication of the Baltic Sea. The air emissions have also other impacts on the environment.

The negative health effects of diesel exhaust due to particles, NO_x, HC, CO, SO_x and other emissions are significant. An estimation of the impact of shipping to human health and other environment can be carried out by using the marginal social cost approach.

3 BACKGROUND OF MARGINAL SOCIAL COSTS

During the last few years, the discussion on the marginal social costs of transportation (Bickel & al, 2006) has been active. The aim of the European Commission (EC) is to charge different modes of transport according to their marginal social costs (CEC 1995). The EC's basic argument was that many elements of the transportation cost — congestion, accidents, environmental and infrastructure maintenance — were either not reflected at all in the current prices or were reflected only in part. In other words, the purpose is to measure the harmful emissions from the transportation by financial values. In spite of the substantial amount of research and policy development (Bickel & al, 2006), the progress on implementing the policy has been very limited.

Examples of external costs of transport are:

1. congestion
2. accidents
3. emissions to air
4. noise
5. effect on the climate change

There are two reasons for a slow progress in the internalization of the marginal social cost approach. First, there are substantial difficulties arise in measuring and valuing these costs, and secondly, because the policy makers are not familiar with the concept of the marginal cost approach. Therefore, several case studies are needed to compare marginal social costs between various modes of transport.

3.1 EU and the method of social marginal costs

There are several examples of using the marginal social costs as a tool for decision making. The EU directive 1999/62/EC ”Eurovignette” and its revision (2006/38/EC) are the base for implementing externalities in the European transport policy. Today, the EU transport regulations include infrastructure charging for heavy goods vehicles on the routes that are a part of the trans-European road network. Trucks using the network cannot be charged for other than infrastructure costs. The draft revision of the directive would expand the route network and give the governments a possibility to charge lorries based on the costs of air pollution, noise and congestion, but not on the climate change or accidents (CEC, 2008).

According to EC, the climate change should be regulated with additional fuel levies or taxes (CEC, 2008). The same basic idea is proposed in the International Maritime Organisation (IMO) to control the ship-originated CO_2 emissions. Due to the nature of the green house gases (GHG) affecting the climate change, the differentiation of taxes is unnecessary and thus a direct tax or an emission trading system would be the best option to cut the emissions. Because the GHG is neglected in the Eurovignette revision draft, the results of this study are also presented without the costs of the CO_2 emissions.

The Commission has proposed that the charge could vary depending on the road type, truck's emission classification and driving time (CEC, 2008). Governments could set charges if necessary but the framework and the rules of the directive must be followed. The rules would include a cap, "maximum chargeable costs" to limit the collected charge. The differentiation of charging is important because the system should be fair, i.e. the charges should be fewer if driving a low emission car or using the charged roads outside of the peak congestion. This paper shows the effect of certain variables to the total emission externalities.

Directive 2006/38/EC: "No later than 10 June 2008, the Commission shall present, after examining all options including environment, noise, congestion and health-related costs, a generally applicable, transparent and comprehensible model for the assessment of all external costs to serve as the basis for future calculations of infrastructure charges. This model shall be accompanied by an impact analysis of the internalisation of external costs for all modes of transport and a strategy for a stepwise implementation of the model for all modes of transport. The report and the model shall be accompanied, if appropriate, by proposals to the European Parliament and the Council for further revision of this Directive."

3.2 The calculation algorithms

In this report, we want to present the suitability of externalities as an indicator for an environmental impact of transport. The increasing traffic and the changing structure of shipping in the Gulf of Finland are used as an example. We have developed an algorithm that calculates the air emissions of ships based on a known emission data from the Baltic Sea area and the Automatic Identification System (AIS) for traffic information of the Gulf of Finland. Emission estimations and future scenarios have been made for six major ship types until year 2015. These future scenario analyses show the effect of the increasing ship traffic in the form of emission externalities. The scenarios show the effect of upcoming regulations to reduce pollution as well as it highlights the crucial variables that could be used in the decision making.

The second algorithm calculates the marginal costs based on the externalities of air pollution of the Russian passenger car transit traffic carried out via Finland. By presenting this case, we want to show how the marginal social cost approach could be used in the decision-making between the modes of transport and help routing the traffic so that its external costs would be minimal.

The two algorithms developed in this study are based on an approach developed in the ExternE project (ExternE, 2008). According to this approach, the Impact Pathway Approach (IPA) builds detailed bottom-up cost estimates and the marginal environmental costs of transport by the used transport mode in time, space and vehicle type. This kind of lateral thinking differs from the more common top-down approaches that introduce the estimates of total cost and allocate them to individual vehicles or traffic flows (Bickel & al, 2006).

3.3 Ship-originated air emissions and the externalities

The main air emission compounds produced by ships' diesel engines are NO_x, SO_x, PM and CO_2. NO_x and SO_x are the two main emissions that contribute to the eutrophication of the seas and the PM emissions are highlighted because of their negative health effects. PM is the most important from the point of view of externalities due to its comparably high price per emitted ton (unit cost) in densely populated areas(Table 3.1). CO_2 is considered as a substance affecting climate change and thus it is not bound to the location of the emission.

Table 3.1 Emission externalities in Euros per ton in 2000 cost level (MINTC 2003)

Compound, €/ton	Open sea (Baltic Sea)	Near coast	Inland waters	Harbour
CO	0.4	2	23	19
HC	137	153	197	148
NO_x	301	397	569	1062
PM	3410	5610	9580	26880
CO_2	32	32	32	32
SO_2	327	547	684	2283

3.4 Air emissions originating from heavy goods vehicles and the externalities

The main air emission compounds produced by trucks' diesel engines are the same as in the case of marine diesels: NO_x, SO_x, PM and CO_2. NO_x and PM are the two main emissions that should remain as the focus. The PM emissions are highlighted in cases where heavy road transport takes place inside urban areas (Table 3.2). The SO_x emissions of road transport have been reduced to a minimum due to the non-sulphur fuels and the CO_2 emissions as a GHG which should be considered separately (chapter 3.1). Additional compounds that are valued are carbon monoxide (CO) and hydrocarbons (HC). Cost of soiling is evaluated in Euros per vehicle kilometre.

Table 3.2 Emission externalities in Euros per ton in 2000 cost level, used for truck transport (MINTC 2003)

Compound	Unit	Urban	Rural	Average
SO_2	€/ton	13421	1994	8322
NO_x	€/ton	1111	435	734
PM2.5	€/ton	201879	6308	103567
CO	€/ton	24	1	16
HC	€/ton	67	67	67
green house gases in CO_2 equivalents	€/ton	32	32	32
soiling	€/vehicle-km	0.0009	0.000009	0.0004

3.5 Passenger car transit via Finland to Russia

With the collapse of the Soviet Union in the beginning of the 1990s, Russia lost most of its ports on the Baltic Sea. Today, the "Finnish route" to the Russian markets is widely used due to the high standard of safety and infrastructure. Therefore, the goods transported via the Finnish route consist mainly of high quality products, including electronics and passenger vehicles (Figure 3.1). The transportation of cars increases every year by ten per cent or more, creating a heavy load on the road infrastructure (Statistics of Finnish Customs 2008). The roads between the main Finnish Southern ports and the Russian border have not been built to carry such a volume of Russian transit.

The majority of the new car transit goes through Finland to Russia (Sergeeva, 2007). Sergeeva considers that a potential challenge for the Russian markets is that the warehousing capacity in Finland diminishes in the near future. In addition, an elemental issue in relation to this theme is the extensive development taking place in the Russian ports. The Russian transport strategy states that these ports aim to increase the level of direct transportation of goods from and to Russia from 75 % in 2003 to 90–95 % by 2020.

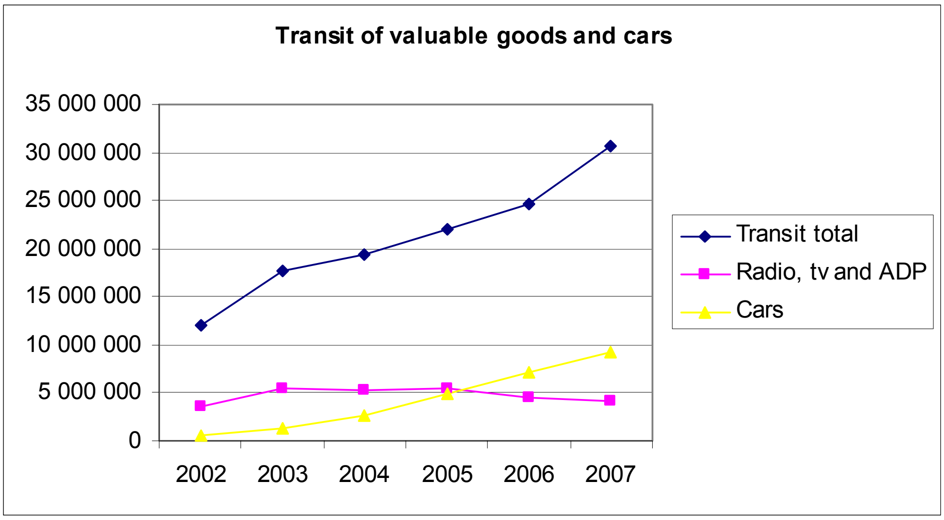

Figure 3.1 Russian total and high-value imports in euros in 1995–2006. (www.gks.ru, 2008)

The Russian transit traffic is a commonplace issue in Finland every year. Only a small part of the cars are transported by rail because of two reasons: first, there is not enough railway wagons suited for car transportation and, secondly, Moscow has not enough suitable space nearby the railways for storing the cars (Ruutikainen & al, 2008). In the border areas, long queues (up to 80 kilometres) of heavily loaded lorries might occur creating serious safety and environmental problems (Loeb & Clarke, 2007). On the other hand, this traffic intensity brings the needed volume for the Finnish ports and logistics companies, creating jobs and tax income (Ojala, 1995, Ollus & Simola, 2006, Tuominen & Himanen, 2007).

During the last few years there has been continuous public discussion about the transit volumes and their effects on the economy, health and safety. This discourse has related to whether such traffic should be concentrated on the ports near the Russian border, e.g. in Kotka and Hamina, instead of the ports that traditionally have been the main car import ports in Finland e.g. the ports of Hanko and Turku (Figure 6.1).

3.6 Automatic Identification System (AIS)

All passenger ships and other vessels above 300 gross tonnages are required to have an operational AIS transponder onboard (IMO, SOLAS). AIS is based on a VHF radio network built on the shores of the Baltic Sea and on the capability of ships to send and receive messages sent by the AIS apparatus. Every ship sends a unique AIS message indicating its movements in real time. AIS was originally developed due to safety reasons but it is also capable to be used for various other purposes.

An AIS message includes two types of information: dynamic and static. The dynamic data consists of navigational information, i.e. heading, speed and location. The static information is always the same and mainly added in the system at the time of installing the transponder. Static information consists of ship attributes i.e. MMSI number, IMO number, call sign, name of the ship, ship type, cargo info and the next port of call. This static information is not always properly written in the transponder and thus not a reliable source of information.

In practice, this means that another method to collect ship attributes has to be generated after the vessel has been identified on the basis of the AIS. The MMSI number is in a key role because every official AIS transponder must have a unique MMSI code. Recognition of the ships is thus based on the MMSI code and the IMO number which is often included in the static message.

The AIS data for this study originates from the GateHouse AIS Statistics which is used for generating and displaying statistical AIS data, and performing analysis on this data. The GateHouse AIS Statistics implements the HELCOM (Helsinki commission) countries contract to collect together the AIS information from the Baltic Sea countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russian federation and Sweden). The whole year of 2007 is represented by 17 individual days with appropriate AIS data (Table 4.6). The dates are chosen to be 20 days apart from each other to minimize errors due to seasonal changes in traffic. Downloading data for every day of the year 2007 would have taken too much time to implement. By this method, we are able to get a reasonably trustworthy amount of ships recognised compared to the total fleet of the Gulf of Finland.

3.7 Calculation algorithms

Two different calculation algorithms were built for this study, both with Microsoft Excel. The first algorithm was developed to calculate the future scenarios of ship-originated air emissions in the Gulf of Finland. The aim was to develop a calculation method which could be used to study the impact of the ship traffic growth and the effect of international maritime regulations on the environment. The impact can be studied by using the externalities of the ship-originated atmospheric emissions as an indicator. Because the calculation of the externalities needs the input information as air emissions in tons for every compound, the emissions of NO_x, SO_x, CO_2, and PM are calculated for each spatial region (open sea, coast, and harbour).

The second algorithm calculates air emissions of specific ship and truck travel distances and converts the produced emissions into externalities. With the results of this algorithm, we show the suitability of the externalities methodology in estimating the environmental impact of different multimodal routes. The algorithm also produces valuable information about the major variables affecting the externalities.

4 GOF EXTERNALITIES: METHODS AND CALCULATIONS

The following chapter describes the basic assumptions and methodology used in the development of the algorithm for the shipborne emission externalities in the Gulf of Finland. Emission externalities calculation is based on the estimation of atmospheric NO_x emissions of shipping. The other emissions are derived from the NO_x emissions with conversion factors (chapter 4.2).

The algorithm has been developed for this study and it is capable of producing numerous scenarios. These estimations are used in the future scenarios of this study. It should be noted that these values are created to serve the calculation algorithm produced in this study and might not be valid for other purposes.

4.1 Estimating annual traffic growth for each ship type

The algorithm is based on a percentile growth of NO_x emissions per annum. The percentile growth is a constant value for each year and characteristic of each ship type considered in this study (Table 4.1). The determination of growth factors is presented below.

Table 4.1 Growth factors per annum for GOF traffic

Ship type	Share of emissions [%]	Growth per annum [%]	Growth factor for 2015 (chapter 4.1)
Tankers	19.0	7.56	1.79
Passenger	20.2	2.06	1.18
Bulk	8.2	0.00	1
general cargo	14.3	0.00	1
Container	12.7	13.1	2.68
Ro-Ro	13.5	1.24	1.10
Total	87.9		

The traffic growth in the Gulf of Finland is mainly dependent on the transport need to and from Russia (Kuronen & al, 2008). Some studies have made assumptions for annual traffic growth of shipping in the Baltic Sea. The variation is from 1.5 - 5.2 % per annum (Stipa & al, 2007 and ENTEC 2002). The traffic growth is difficult to predict and it could be even higher in the next few years, and especially in the case of the Gulf of Finland. We have used the percentile growths for several ship types per annum. Results are tabulated in the Table 4.1.

4.1.1 Tanker traffic growth

Estimating of percentile traffic growth for tankers is produced based on the growth of liquid bulk cargo in the harbours in the Gulf of Finland. It has been assumed that:

1. All traffic increase consists of crude oil tankers only.
2. Traffic increase consists of ships to and from Russian ports only.
3. Crude oil tankers are not able to increase their load factor from the current load factor.
4. Tanker traffic will increase at least with the same rate as the oil cargo amount because the size of crude oil tankers cannot grow anymore.
5. Ship is arriving to a Russian port empty and it is full when leaving.

Finnish Environmental Institute (SYKE) estimated that oil transport in the Gulf of Finland was 146 million tons (in 2007) and the corresponding value for 2015 would be 262 million tons (Hietala, 2008). This indicates that in 2015 the transported oil amount is 1.8 times higher than in 2007. The same value can be used as a growth rate of the traffic increase based on the assumptions mentioned above.

By using the factor 1.8 to represent the traffic growth from 2007 to 2015, and having the assumption that the NO_x emissions will increase linearly with the traffic growth, the externalities algorithm can be used to iterate the percentile traffic growth per annum for tankers, which is 7.56 %.

The tanker traffic in the Gulf of Finland can be assumed to be different when comparing the traffic to and from Finland. We have assumed that the major part of the tanker traffic growth is crude oil transportation which has only a minor share in the total liquid bulk transportation to and from Finland (FMA 2008b). Figure 4.1 presents the tanker traffic and cargo tonnage in the case of Finland. It can be seen that the amount of ship calls stays constant when the cargo tonnage grows. This could be due to the growing ship size (growing capacity) and higher load rate. Nevertheless in this study, it has been assumed that the tanker traffic will grow linearly with the cargo tonnage as presented earlier.

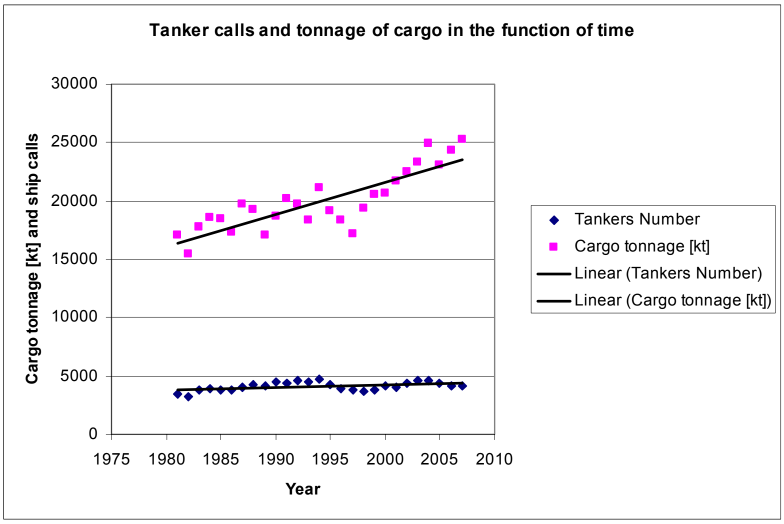

Figure 4.1 Tankers ship calls and cargo tonnage in Finland in recent years (FMA 2008b)

4.1.2 General cargo ship traffic growth

The strong containerization affects the composition of general cargo. According to the Lloyd's Register (Lloyd's Register & al, 2007), the growth rate of general cargo is the highest when compared to dry or liquid bulk. This global estimation includes containers in the classification group of general cargo. The extraction of containerized cargo from the general cargo leads to a decreasing growth rate of general cargo. This has been valid with global data over the last couple of years. However, the Baltic Sea cannot be considered as an average sea area with general cargo traffic due to the intensive feedering. Nevertheless, it can be concluded that the growth in the container ship traffic in the Baltic Sea is partly due to the flow of containerized cargo from general cargo ships to container ships. This conclusion supports the very high growth rate of container ship traffic determined later.

The prediction of the general cargo ship traffic growth in the Gulf of Finland is extremely difficult. Lloyd's Register (Lloyd's Register & al, 2007) estimates a slight global decrease in the general cargo transport but due to intensive feedering in the BSR we can assume that the decrease rate is not significant. In our calculations we used a 0 % growth per annum for the general cargo ships.

4.1.3 Container ship traffic growth

The transportation of containers is increasing and the intensive growth of container transport can be estimated in the Gulf of Finland (Kuronen & al, 2008). The Port of Helsinki opens its new container terminal to Vuosaari in 2008 and the Port of Ust-Luga and the other Russian ports are heavily investing in the handling of containers. It has been estimated that the global container trade volumes from 2002 to 2015 would be 6.6 per cent, compared to the 8.5 per cent per annum during 1980-2002 (United Nations, 2005). The average growth rate through to 2010 has been estimated at 7.5 per cent per annum, whereas for the following five years, the growth rate is expected to decline to 5.0 per cent (United Nations, 2005). The global figures are lower than the ones determined in this project (presented below).

The growth in the container transportation in units is not directly comparable with the growth of the container vessel traffic (Figure 4.2). The cargo tonnage growth rate is higher than the number of ship calls. This can be due to the growth of the load capacity and load factor of vessels. The development in the container vessel traffic can be assumed to be similar.

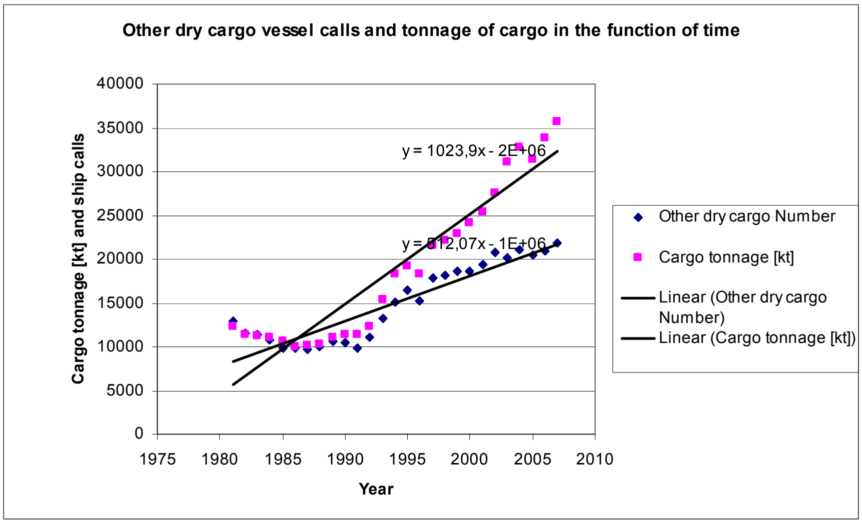

Figure 4.2 Development of "other dry cargo" tonnage and "other dry cargo" vessel calls in Finland (FMA 2008b)

The estimation of container transportation for the year 2015 has been collected into Table 4.2 in TEUs. Calculating the transported TEUs for each year is possible by using the 2007 and 2015 TEU figures (Table 4.2). The TEUs per annum in 2003 - 2020 are extrapolated and presented in Table 4.3.

Table 4.2 TEU transportation in the Gulf of Finland in 2007 and 2015 (Kuronen & al, 2008)

	2007 TEU	2015 TEU
Hanko	60 618	91 730
Helsinki	431 404	652 823
Kotka	563 042	852 024
Hamina	199 002	301 140
Finland	1 254 066	1 897 718
St. Petersburg	1 697 720	x
Ust-Luga		x
Russia	1 697 720	10 055 726
Tallinn	180 911	x
Vene-Balti	286	x
Estonia	181 197	627 220
Total	2 532 046	12 580 664

The average TEU capacity of a container ship was 1000 TEU in 2007 (FMA 2008a). The corresponding capacity has been assumed to grow to 2000-3000 TEU by the year 2015. Using the TEU-based transportation statistics in the Gulf of Finland (Table 4.3) and combining them with the vessel growth presented previously, we are able to create a traffic growth data for the years 2007-2020 (Table 4.4).

Table 4.3 Development of container transportation in the Gulf of Finland

TEU base values	Russia TEU	Finland TEU	Estonia TEU	
2003	650000			
2007	1 697 720	1 254 066	181 197	
2020	15279480	2 300 000	905985	
Year	**Russia TEU**	**Finland TEU**	**Estonia TEU**	**Total**
2003	650 000	932 240	-41 815	1 540 425
2004	911 930	1 012 697	13 938	1 938 565
2005	1 173 860	1 093 153	69 691	2 336 704
2006	1 435 790	1 173 610	125 444	2 734 844
2007	1 697 720	1 254 066	181 197	3 132 983
2008	2 742 471	1 334 522	236 950	4 313 943
2009	3 787 222	1 414 979	292 703	5 494 903
2010	4 831 972	1 495 435	348 456	6 675 863
2011	5 876 723	1 575 892	404 209	7 856 824
2012	6 921 474	1 656 348	459 962	9 037 784
2013	7 966 225	1 736 805	515 715	10 218 744
2014	9 010 975	1 817 261	571 467	11 399 704
2015	10 055 726	1 897 718	627 220	12 580 664
2016	11 100 477	1 978 174	682 973	13 761 624
2017	12 145 228	2 058 631	738 726	14 942 585
2018	13 189 978	2 139 087	794 479	16 123 545
2019	14 234 729	2 219 544	850 232	17 304 505
2020	15 279 480	2 300 000	905 985	18 485 465

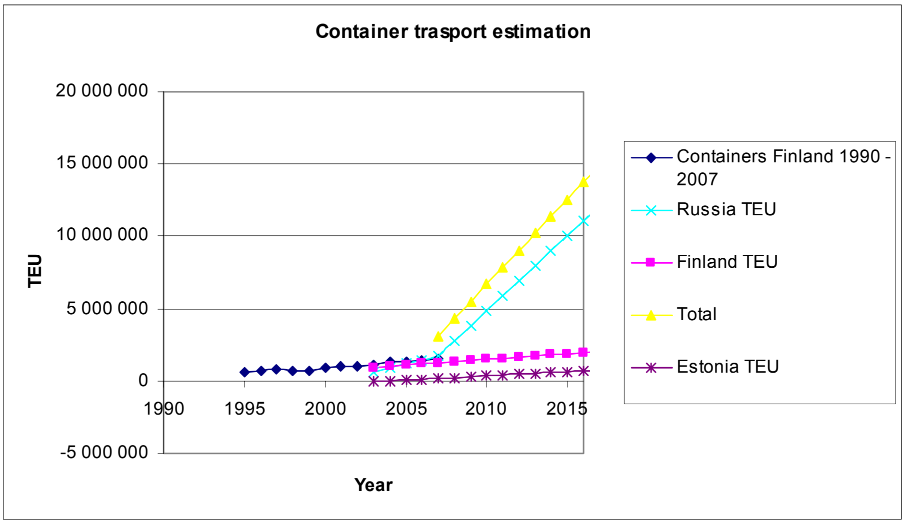

Figure 4.3 Growth of container transportation to and from Estonia, Finland and Russia.

Estimating the percentile growth of the container ship traffic in the GOF is based on the information in Table 4.4. By taking into account the assumption of the growth in ship sizes and the TEU transportation demand in the GOF, the total ship number in 2015 is 2.7 times the 2007 ship number. This growth corresponds with the percentile growth of 13.1 % per annum for container vessels (Table 4.1).

Table 4.4 Calculated development of container vessel traffic in the Gulf of Finland

	Number of container vessels				
Year	Russia	Finland	Estonia	Total	Average TEU size of a vessel
2003	650	932	-42	1 540	1 000
2004	842	935	13	1 789	1 083
2005	1 006	937	60	2 003	1 167
2006	1 149	939	100	2 188	1 250
2007	1 273	941	136	2 350	1 333
2008	1 936	942	167	3 045	1 417
2009	2 525	943	195	3 663	1 500
2010	3 052	944	220	4 216	1 583
2011	3 526	946	243	4 714	1 667
2012	3 955	946	263	5 164	1 750
2013	4 345	947	281	5 574	1 833
2014	4 701	948	298	5 948	1 917
2015	5 028	949	314	6 290	2 000
2016	5 328	950	328	6 606	2 083
2017	5 605	950	341	6 897	2 167
2018	5 862	951	353	7 166	2 250
2019	6 101	951	364	7 416	2 333
2020	6 323	952	375	7 649	2 417

4.1.4 Passenger and Ro-Ro ship traffic growth

The Finnish national data (FMA 2008b) has been used to estimate the growth of the passenger ship traffic. Helsinki and Tallinn represent the major passenger ports along with St. Petersburg in the Gulf of Finland.

The number of ship calls will be 1.18 times higher in 2015 than in 2007 if the traffic increase continues as it was in 2007 in Finland. The Finnish national data is suitable for representing the passenger transport growth in the GOF because the growth can be assumed to be similar with the Finnish national growth. This assumption means that the passenger transport demand is similar in Finland than in the GOF.

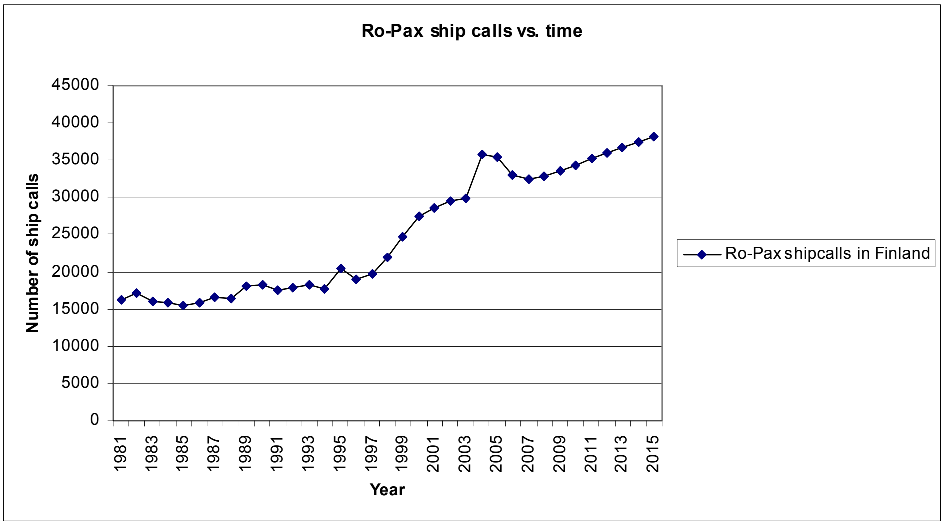

Figure 4.4 Estimation of ship calls growth in Finland until 2015. Growth equals to 2.06 % per annum in 2007-2015 (based on the data of FMA 2008b).

The number of passenger ship calls is estimated to be 1.18 times higher in 2015 than in 2007. This figure represents the amount of traffic growth which corresponds with the growth of the NO_x emissions. This leads to the NO_x emission growth of 2.06 % per annum (Table 4.1). The growth rate of the Finnish national data was used to represent the growth of passenger ship and Ro-Ro ship transport. A similar assumption with the other ship types would lead to error due to differences between the GOF countries.

The Ro-Ro ship traffic is estimated to grow 1.1 times higher in 2015 than in 2007. This growth rate is based on the Finnish national statistics (FMA 2008b). The estimation is produced similarly as in the case of the passenger ships. The NO_x emission growth for the Ro-Ro ships per annum is 1.24 %.

4.1.5 Bulk vessel traffic growth

A bulk cargo transport is estimated to grow 1.3 times higher in 2015 than in 2007 (Kuronen & al, 2008) in the GOF. Converting this information into traffic growth is problematic. The growth in ship sizes and the increase of the load rate may diminish the need for new ships and extra traffic. Because of such difficulties in the estimation of traffic increase and because of uncertainties in the cargo transport growth (Kuronen & al, 2008), it is assumed that the bulk vessel traffic continues as constant until 2015, which means a traffic growth percentage (and NO_x emission growth) of 0 % per annum.

Table 4.5 Bulk cargo growth in the Gulf of Finland (Kuronen & al, 2008)

	Total 2007	Factor	Total 2015
Dry bulk	41.3	1.303	53.8
Liquid bulk	145.5	1.374	200.0
Other dry cargo	68.4	1.299	88.9
Total	255.2		342.6

4.2 Modelling of emissions and externalities in the Gulf of Finland

Modelling of the externalities of shipping requires a calculation of ship-originated atmospheric emissions. The main purpose of the algorithm development is to draw up a calculation of the total NO_x emissions of shipping. The NO_x emissions of shipping in the Gulf of Finland were 53 158 tons (Wahlström & al, 2006) in 2000. This figure is used as a base value in adjusting the emission scenario in Figure 4.7.

The second basic assumption is the ratio between the number of ships and the annual NO_x output for each ship type (Figure 4.5, Stipa & al, 2007). The algorithm uses the Gulf of Finland traffic data (HELCOM AIS database) and with the information on Baltic shipping (in Figure 4.5) it is possible to create an estimation of the ship-originated NO_x emissions for the Gulf of Finland (Equation 1). The AIS data used for the 2007 traffic analysis is based on the samples from the examined 17 days (Table 4.6).

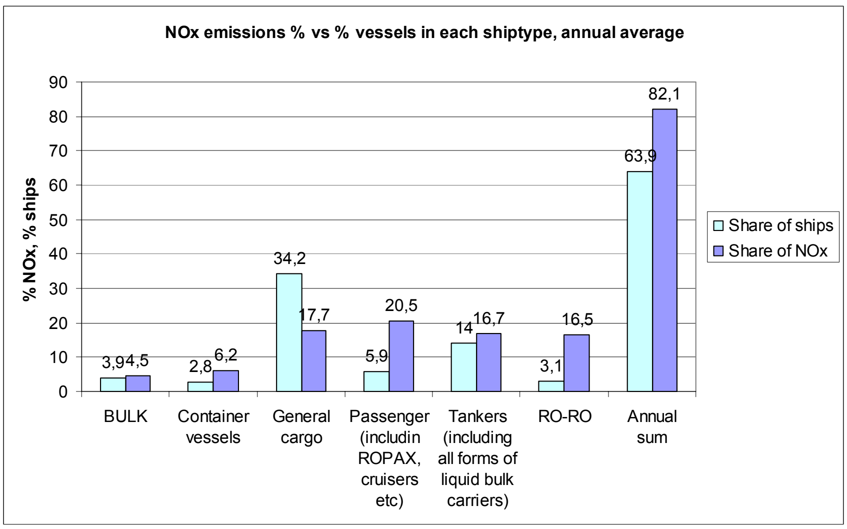

Figure 4.5 Contribution of ships to annual NO_x output of 370 kt in each of the ship types compared to the proportion of the total number of ships (Stipa & al, 2007)

An estimation of the growth of NO_x emissions with a constant figure in percentages per annum leads to a growing error. The future scenarios reaching further than the year 2015 would require modifications to the calculation method. Because of the renewal of vessels and the technical development of engines, the method would need a population theory behind the calculations. Tier 1, 2 and 3 regulations would diminish the growth of NO_x emissions and thus the calculation of other emission compounds could not be based on the NO_x.

Table 4.6 The analyzed 17 days of AIS data

1.4.2007	30.7.2007
17.12.2007	19.8.2007
20.2.2007	8.9.2007
12.3.2007	28.9.2007
21.4.2007	18.10.2007
11.5.2007	7.11.2007
31.5.2007	27.11.2007
20.6.2007	1.2.2007
10.7.2007	

4.3 Analysing the AIS data

The total number of ships found during the examined 17 days on the Gulf of Finland was 2914. From these ships, only those vessels included in the following ship types were taken into account in this study:

1. Bulk vessels
2. Container vessels
3. General cargo
4. Passenger (including ROPAX, cruisers etc.)
5. Tankers (including all forms of liquid bulk carriers)
6. Ro-Ro

These ship types were chosen because they represent the majority of air emissions, andestimating their growth is relatively simple. The share of NO_x emissions in the Gulf of Finland per ship type can be calculated (Equation 1) based on the BSR data. The share of emissions per ship type (for the BSR and GOF) are tabulated in Table 4.7.

Equation 1: $$\frac{ships(BSR)}{NOx(BSR)} = \frac{ships(GOF)}{NOx(GOF)}$$

For example:

$$\frac{3.9(bulkBSR)}{4.5(bulkBSR)} = \frac{7.1(bulkGOF)}{NOx(bulkGOF)}$$
$$\Rightarrow NOx(bulkGOF) = \frac{7.1(bulkGOF)}{\left(\frac{3.9(bulkBSR)}{4.5(bulkBSR)}\right)}$$
$$\Rightarrow NOx(bulkGOF) = 8.2$$

Table 4.7 Ships seen during the examined 17 days in the Gulf of Finland

	Number of ships in GOF (17 days sample)	share of ships in BSR [%] (Stipa & al, 2007)	share of NO_x BSR [%] (Stipa & al, 2007)	share of ships in GOF [%]	share of NO_x [%]
Bulk	208	3.9	4.5	7.1	8.2
Container vessels	167	2.8	6.2	5.7	12.7
General cargo	805	34.2	17.7	27.6	14.3
Passenger (including ROPAX, cruisers etc)	169	5.9	20.5	5.8	20.2
Tankers (including all forms of liquid bulk carriers)	464	14	16.7	15.9	19.0
Ro-Ro	74	3.1	16.5	2.5	13.5
sum	1887	63.9	82.1	64.8	87.9
total (all ship types)	2914				

By using the Equation 1, we can create Table 4.7 and Figure 4.6. By summarizing the shares of NO_x in the GOF we get 87.9 % when the corresponding value for the BSR is 82.1 %. This indicates that the chosen six ship types represent a higher share of the total NO_x emissions in the GOF when compared to the BSR. Nevertheless, the 87.8 per cent is a high enough figure to consider these ship types as a reliable base for constructing the whole NO_x emissions of shipping in the GOF.

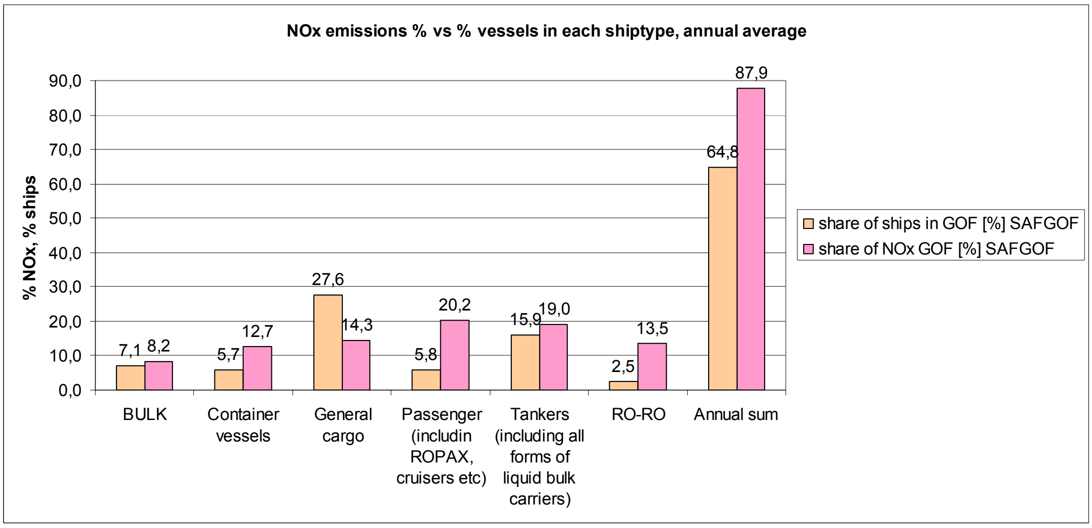

Figure 4.6 The share of ships and produced NO_x in the GOF, produced using Equation 1, annual average

4.3.1 Adjusting the 2007 – 2015 NO_x emissions

Emissions from year 2000 (53 158 tons, Wahlström & al, 2006) are used as a base value for the emission calculations. Because of the time difference of the base emissions and ship traffic data, we have to adjust the 2007 - 2015 emissions to a correct level. Adding an exponential trend line to the graphical presentation of 2007 – 2015 emissions shows a cross point in 2000. The 2007 NO_x emissions can be determined by multiplying the 2007 – 2015 emissions with 1.62. This has been done in Figure 4.7.

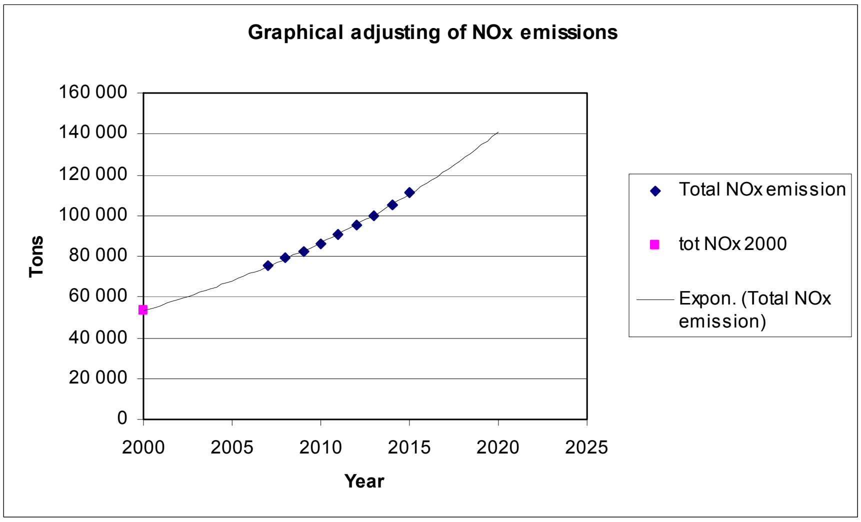

Figure 4.7 Graphical estimation of annual NO_x emission in the GOF in 2007. The exponential trend line is adjusted by iteration to cross the known NO_x emission in 2000 by using a multiplying factor (in this case 1.62).

4.3.2 Factors to calculate other emissions from NO_x emission

The calculation of other than the NO_x emissions is done by multiplying the annual emissions of NO_x with a certain factor. The factors are presented in Table 4.8 below. The only exception is the PM emissions that are dependent on the SO_x emissions. Thus, a more accurate evaluation can be made by binding the PM emissions which are dependent on the SO_x emissions. This is essential because in the future regulations demand radical reductions in the sulphur content of marine fuels, i.e. on 1 March 2010 onwards the marine fuel may not contain more than 1.0 % of sulphur (Baltic Sea SECA). The effects of this regulation can be clearly seen in the scenarios presented in Figure 5.3. It should be noted that the algorithm calculates all values per annum; the 1.0 % sulphur limit is taken into account from 1 January 2010 onwards (creating an error of three months).

Vessels in the EU ports have to use 0.1 %-S fuel after 1 January 2010. This regulation will have a radical effect on the externalities but not on the total SO_x emissions in the GOF. The major effect of the use of extra low sulphur fuels in ports (possibly marine diesel oil (MDO) and marine gas oil (MGO)) is due to the considerably lower PM emissions in the port area which leads to a radical decrease of externalities.

Table 4.8 Emission conversion factors

Emission conversion factors			
	NO_x	SO_x	Source:
SO_x	0.4		Jalkanen & al, 2008
PM		0.11	Stipa & al, 2007
CO_2	48.6		Stipa & al, 2007
CO_2	46.2		Mäkelä & al, 2008
CO_2	41.3		ENTEC, 2002

The SO_x emissions are linearly dependent on the sulphur content of the fuel. In practice, all the sulphur in the fuel is oxidized to SO_x similarly as all carbon is oxidised to CO_x (depending on the amount of oxygen also to CO and CO_2). The PM emissions are dependent on the sulphur and ash content of the fuel as well as on the burning process in the engine, thus not acting similarly as the SO_x and CO_2. However, in this study the PM emissions are assumed as linearly dependent on the SO_x emissions.

4.3.3 Spatial allocation of emissions

The calculation of the emission externalities requires a spatial allocation of the emissions. This allocation highlights the costs of emissions that are emitted near densely populated areas. The spatial allocation of CO_2 is not necessary because the compound has no effects that are dependent on the location of the emission source.

The division of the calculated air emissions of shipping has been carried out by estimating a share of the total NO_x allocated for ports, near coast and open sea. The estimation is based on the information about shipping to and from European ports (Entec 2002).

Table 4.9 Spatial allocation of emissions, share of emissions [%]

	Ports	Near coast	Open Sea
NO_x	5 %	2 %	93 %
SO_x	7 %	2 %	91 %
PM	7 %	2 %	91 %

5 THE GOF: RESULTS AND SENSITIVITY ANALYSIS

In this chapter, we present the total externalities for each scenario as the prime result. Other results are by-products of the externalities calculation. All results are analysed critically.

5.1 Results

The externalities are presented in Euros (at the cost level of 2000). The scenarios are developed from the year 2007 until 2015 for six major ship types in the Baltic Sea. These ships represent almost 88 % (Table 5.1) of the total NO_x emissions in the Gulf of Finland (based on the Baltic Sea shipping results (Stipa & al, 2007) that are converted by using the AIS data from the GOF).

The calculation of the shipborne externalities demands an estimation of the emissions. The following paragraphs show the results for each emission compound and the spatial division of the emissions.

Table 5.1 Comparison of GOF fleet and NO_x emissions with BSR fleet

	Number of ships in GOF (17 days sample)	Share of ships in BSR [%] (Stipa & al, 2007)	Share of NO_x in BSR [%] (Stipa & al, 2007)	Share of ships in GOF [%]	Share of NO_x [%]
Bulk vessels	208	3.9	4.5	7.1	8.2
Container vessels	167	2.8	6.2	5.7	12.7
General cargo vessels	805	34.2	17.7	27.6	14.3
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Tankers (including all forms of liquid bulk carriers)	464	14	16.7	15.9	19.0
RO-RO vessels	74	3.1	16.5	2.5	13.5
sum	1887	63.9	82.1	64.8	87.9
total (all ship types)	2914				

5.1.1 Emissions in the Gulf of Finland

The total NO_x emission in the Gulf of Finland from the six ship types was almost 75.7 kilotons (Table 5.2) in 2007. The order of the ship types starting from the most pollutant is:

1. Passenger vessels (including cruisers and ROPAX vessels)
2. Tankers
3. General cargo vessels
4. Ro-Ro vessels
5. Container vessels
6. Bulk vessels

Table 5.2 The total emissions of shipping in the Gulf of Finland, 2007

Ship types	Tanker	Passenger	Bulk	Container	General Cargo	RORO	Total
Year	2007						
NO_x [tons]	16 357	17 353	7 093	10 928	12 312	11 626	75 669
SO_x [tons]	6 543	6 941	2 837	4 371	4 925	4 925	30 273
CO_2 [tons]	794 944	843 372	344 700	531 105	598 375	565 698	3 678 194
PM [tons]	720	764	312	481	542	512	8 667

In the future scenarios, the traffic growth for each ship type is estimated up to 2015 and the results are presented in Figure 5.1. Due to the different growth factors, the order will change in 2015 (Table 5.3) and it will be as follows:

1. Tankers
2. Container vessels
3. Passenger vessels
4. Ro-Ro vessels
5. General cargo vessels
6. Bulk vessels

Table 5.3 The total emissions of shipping in the Gulf of Finland, 2015

Ship types	Tanker	Passenger	Bulk	Container	General Cargo	RORO	Total
Year	2015						
NO_x [tons]	29 303	20 428	7 093	29 258	12 312	12 846	111 568
SO_x [tons]	774	539	187	772	325	339	2 937
CO_2 [tons]	1 424 109	992 804	344 700	1 421 940	598 375	624 312	5 406 240
PM [tons]	85	59	21	85	36	37	323

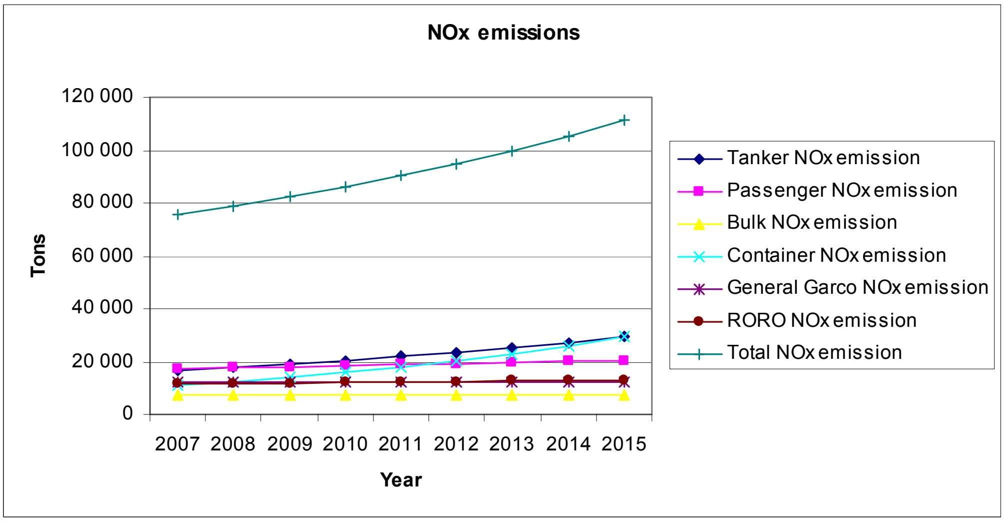

Figure 5.1 NO_x emissions in tons per year in the Gulf of Finland

The NO_x emissions are estimated to be 112 kilotons in 2015, which is more than a double the amount which served as the base for the calculation: 53 158 tons in 2000 (Wahlström & al, 2006) and 1.5 times more than in 2007. However, it can be predicted that the increase of the NO_x emissions will slow down because of the Tier 2 and 3 regulations (IMO, MARPOL Annex VI) for new ships and for the renewal of ships. This result does not include the effect of the renewal of ships because the time interval is comparatively short and the effect would be insignificant.

The NO_x and CO_2 emissions will grow alongside with the traffic growth (Figure 5.1 and Figure 5.2). The lifecycle of a ship in the Baltic Sea is about 25 years. The renewal is an important factor because of the Tier 1, 2 and 3 regulations (IMO, 2008). Especially the Tier 2 (and the Tier 3 in the future) has an effect on the NO_x emissions because the ships built after 2010 must have 20 % less NO_x emissions compared to the Tier 1 level which has been in force as of 1 January 2000.

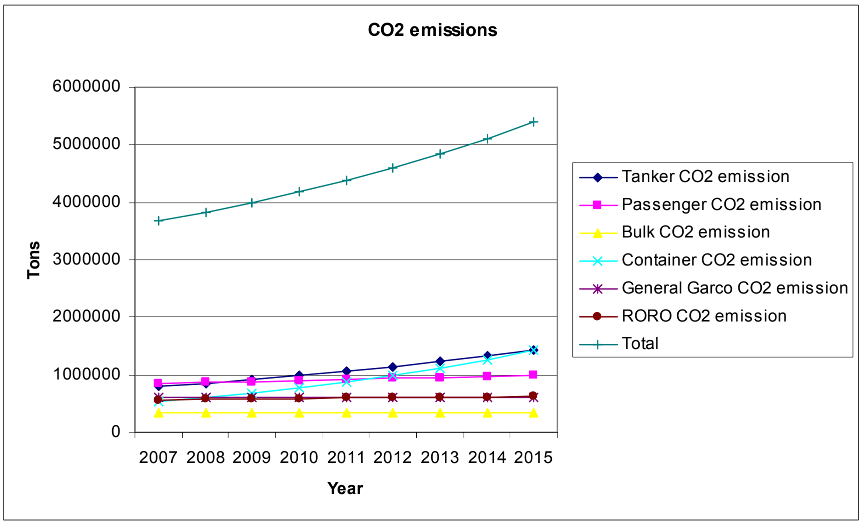

Figure 5.2 CO_2 emissions in tons per year in the Gulf of Finland

The SO_x (Figure 5.3) and PM emissions (Figure 5.4) from shipping have the most significant change of quantity in 2007 - 2015. This is due to the new MARPOL Annex VI regulation for sulphur content in the marine fuels in SECA area. The effect of the decrease of the sulphur maximum from 1.5 % to 1.0 % in 2010 and to 0.1 % in 2015 are presented in the graphs (Figure 5.3 and Figure 5.4). After the dramatic decrease in 2015 the SO_x and PM emissions (and their externalities) start to increase again alongside with the traffic growth.

Another regulation affecting the SO_x emissions is the EU provision for sulphur content of fuels used in ships at berth. This regulation must be followed by all ships that call at an EU port after 1 January 2010. These ships must use a fuel with a 0.1 % sulphur content while berthing (with some exceptions). Despite of the considerable amount of traffic to the non-EU ports in the GOF, it has been assumed that every ship use 0.1 % fuel at port after 2010. Other scenarios are presented later in this paper with the externalities calculation.

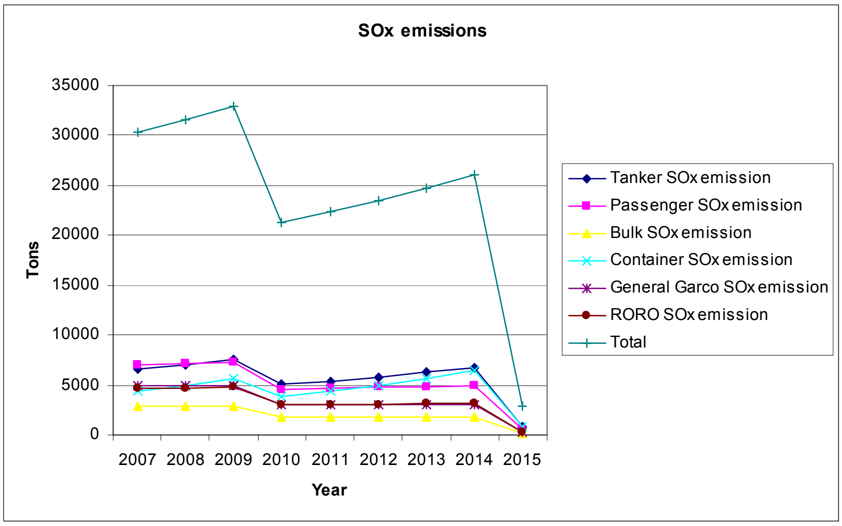

Figure 5.3 SO_x emissions in tons per year in the Gulf of Finland

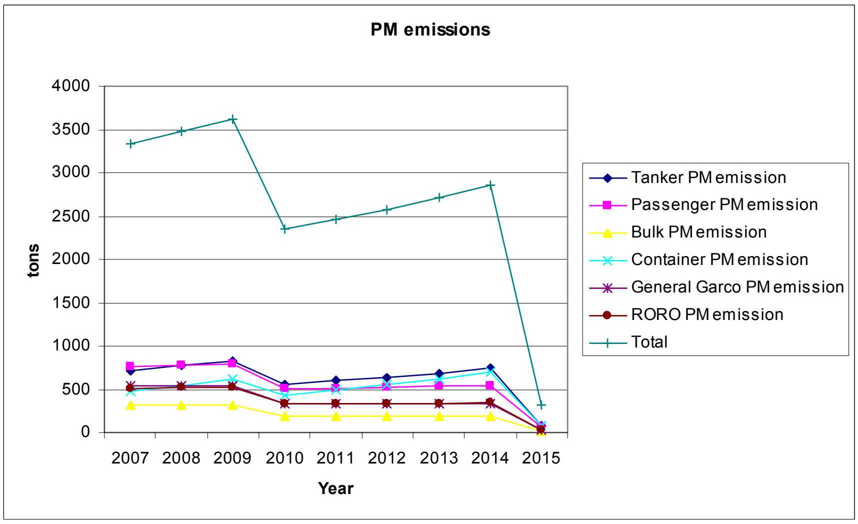

Figure 5.4 PM emissions in tons per year in the Gulf of Finland

5.1.2 Emissions in harbour, at coast and open sea

The ship-originated atmospheric emissions (NO_x, SO_x and PM) have been allocated to three location categories: open sea, near coast and harbour. Because of this allocation, it is possible to use the three types of unit costs tabulated in the Table 3.1. Figure 5.5 shows the NO_x emission allocation. The CO_2 allocation is not necessary because CO_2 is a compound contributing to climate change having the same unit cost in every category.

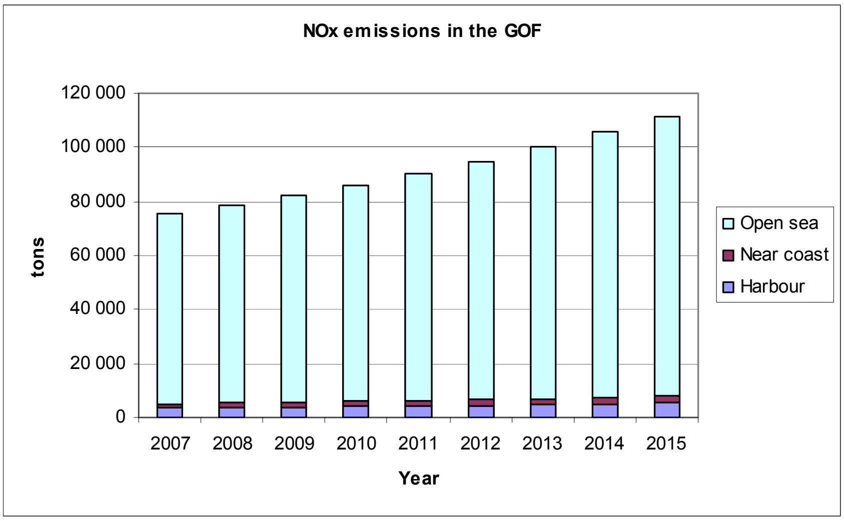

Figure 5.5 Spatial allocation of NO_x emissions in the GOF

The effect of the upcoming EU regulation can be seen when observing tanker emissions (Figure 5.6). The sulphur level cap of 0.1 % will reduce the sulphur and PM emission dramatically. The effect can be clearly seen also in the harbour externalities levels (Figure 5.11).

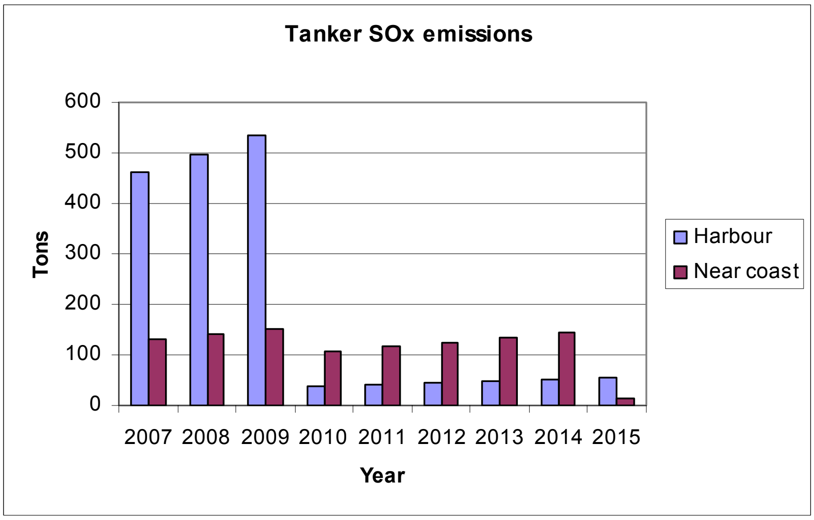

Figure 5.6 Effect of changing regulation of fuel quality in SECA and at berth

5.1.3 Emission externalities in the Gulf of Finland

Converting the emissions to externalities has been done as follows: after the allocation of emissions to different spatial classes (harbour, coast and open sea) the emission tons are multiplied with the corresponding cost value (Table 3.1). The externalities of each compound per shiptype are presented in Appendix 1.

The total cost of atmospheric emissions of shipping in the GOF was almost 175 million Euros in 2007. Costs increase in the future because of traffic growth. The externalities are estimated to total 214 million Euros in 2015 which is about 1.2 times higher than in 2007.

Table 5.4 Emission externalities of shipping in the GOF 2007 – 2015 in Euros (in 2000 cost level)

Year	Tanker	Passenger	Bulk	Container	General cargo	RORO	Total
2007	37 749 301	40 048 943	16 368 683	25 220 438	28 414 862	26 857 470	174 659 698
2008	40 603 149	40 873 951	16 368 683	28 524 316	28 414 862	27 200 793	181 985 754
2009	43 672 747	41 715 955	16 368 683	32 261 001	28 414 862	27 549 722	189 982 969
2010	42 330 666	38 366 444	14 750 527	32 880 185	25 605 859	25 148 881	179 082 562
2011	45 530 864	39 156 793	14 750 527	37 187 489	25 605 859	25 475 615	187 707 147
2012	48 972 998	39 963 423	14 750 527	42 059 050	25 605 859	25 808 351	197 160 207
2013	52 675 356	40 786 669	14 750 527	47 568 785	25 605 859	26 147 419	207 534 616
2014	56 657 613	41 626 875	14 750 527	53 800 296	25 605 859	26 493 186	218 934 356
2015	56 333 313	39 272 233	13 635 271	56 247 535	23 669 853	24 826 140	213 984 345

A notable change will take place in 2010 and 2015 when the SECA area regulations enter into force (Figure 5.7). The 1.0 % sulphur limit in fuel decreases all externalities, except in the case of container vessels. This is because of the very aggressive growth of container vessel traffic. The externalities of container vessels will exceed the level of those of tankers at the end of our study time margin. The externalities trend starts to grow again after 2015 and the effect of 0.1 % sulphur limit in the SECA only slows down the increase of the total externalities.

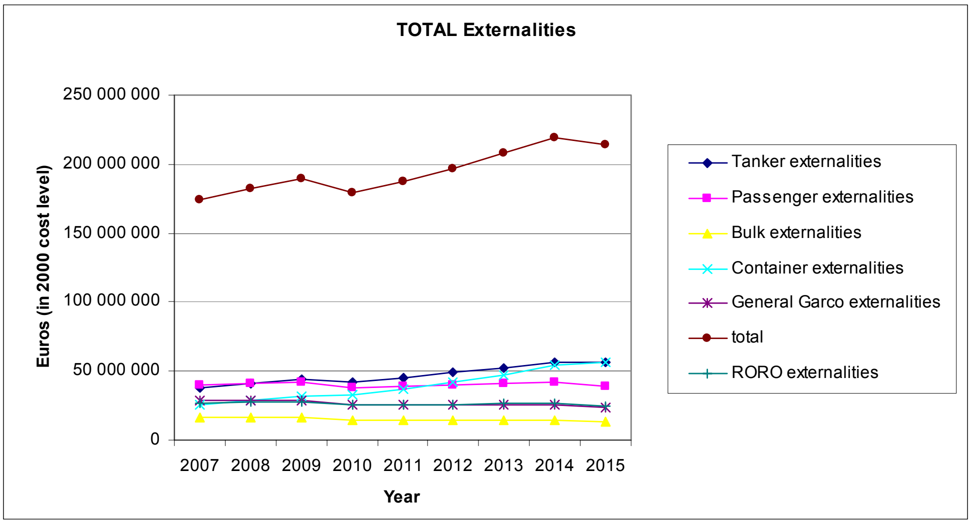

Figure 5.7 Emission externalities per year in the Gulf of Finland

By excluding the externalities of climate change (CO_2 emissions), it is possible to estimate the efficiency of the regulations which enter into force in 2010 and 2015. It will take a long time to exceed the saved externalities.

Table 5.5 The total externalities excluding the externalities of climate change

Year	Tanker	Passenger	Bulk	Container	General Cargo	RORO	total
2007	12 311 079	13 061 055	5 338 275	8 225 074	9 266 863	8 755 146	56 957 492
2008	13 241 796	13 330 113	5 338 275	9 302 559	9 266 863	8 874 001	59 353 607
2009	14 242 876	13 604 713	5 338 275	10 521 194	9 266 863	8 995 678	61 969 599
2010	10 675 897	9 676 111	3 720 119	8 292 463	6 457 860	6 364 766	45 187 216
2011	11 482 995	9 875 439	3 720 119	9 378 775	6 457 860	6 458 578	47 373 766
2012	12 351 109	10 078 873	3 720 119	10 607 395	6 457 860	6 555 502	49 770 859
2013	13 284 853	10 286 498	3 720 119	11 996 964	6 457 860	6 655 835	52 402 128
2014	14 289 188	10 498 399	3 720 119	13 568 566	6 457 860	6 759 906	55 294 039
2015	10 761 835	7 502 511	2 604 863	10 745 448	4 521 855	4 848 168	40 984 679

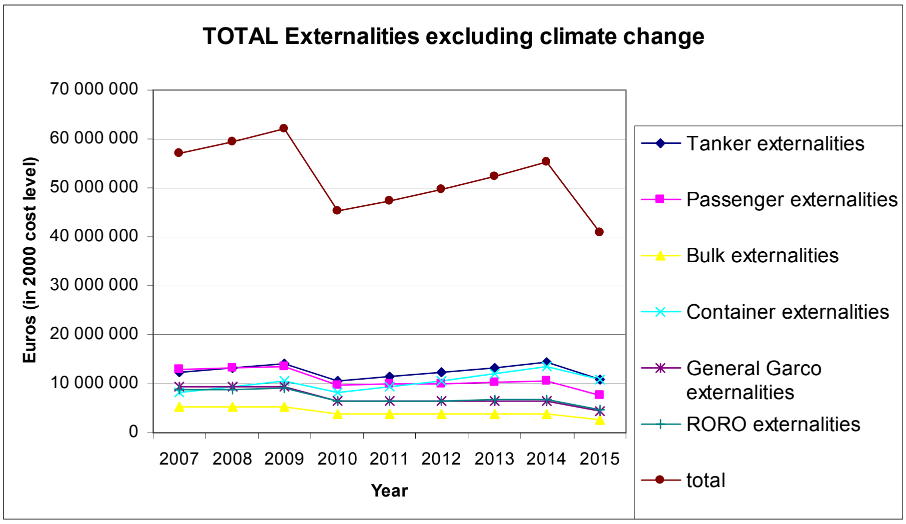

Figure 5.8 The total externalities excluding the externalities of climate change

The allocation of externalities by compound shows the comparatively massive influence of the CO_2 emissions (Figure 5.9). Despite of their low cost of 32 Euros per ton, the total externalities rise to almost 118 million Euros (in 2007). This is about 4.6 times higher than the sum of the second externality in order (NO_x): 26 million Euros (PM 17 and SO_x 14 million Euros). The dominant role of the CO_2 should be considered with extra care. The unit cost used for the CO_2 might be an overestimate (FMA 2002). This does not affect the comparison between the externalities of ship types because the error will be the same for every actor.

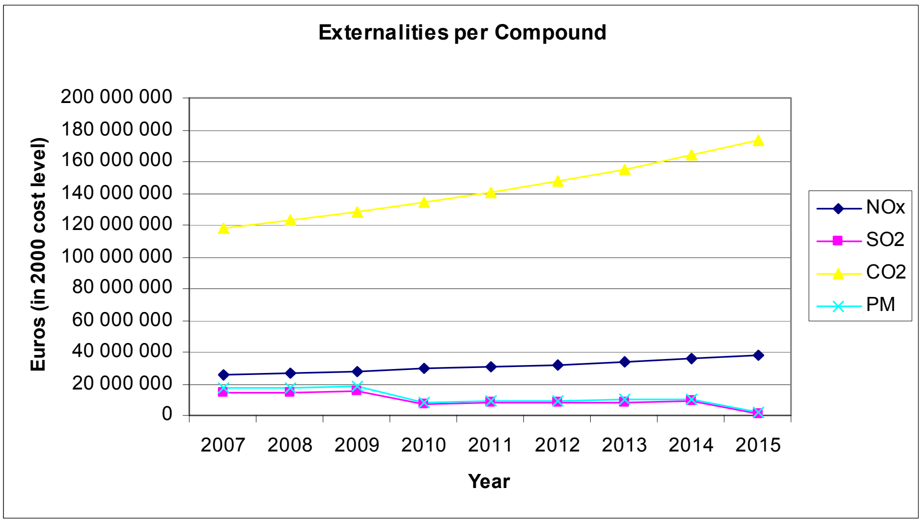

Figure 5.9 Emission externalities per compound

5.1.4 Emission externalities in the ports of the GOF

The externalities in ports committed by ships are highly dependent on fuel quality. The amount of sulphur in fuel determines the amount of SO_x and the PM emissions as discussed earlier. The regulations decreasing the SO_x and PM emissions in ports are shown in Figure 5.10. However, in the case of container vessels the gained reduction in costs is compensated with the traffic growth of four years.

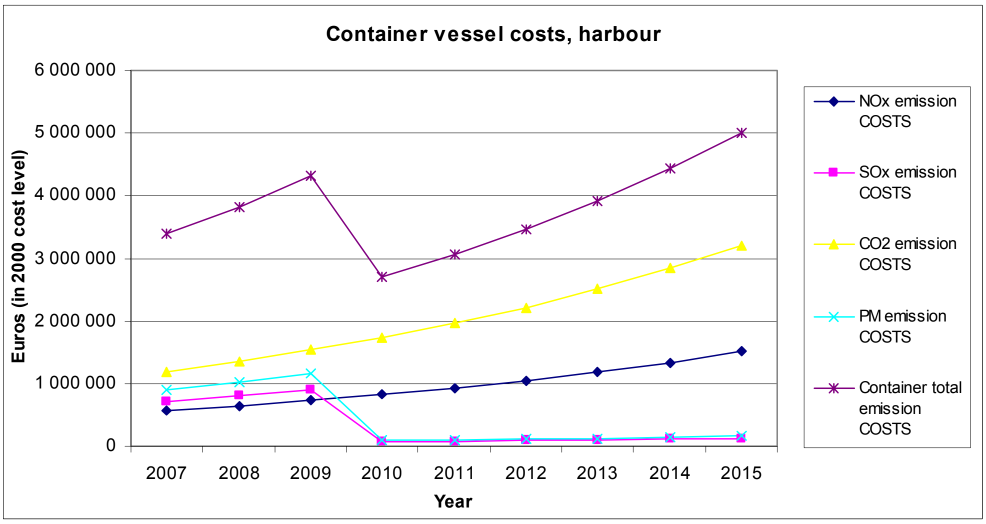

Figure 5.10 Costs of container vessels in the ports of the Gulf of Finland

The total emission externalities in ports excluding the externalities of climate change are presented in Figure 5.11. Excluding the CO_2 externalities helps to illustrate the efficiency of the EU directive more clearly. The emissions externalities concerning especially human health (SO_x, NO_x and PM) will decrease more than 70 % in the ports of the GOF in 2010.

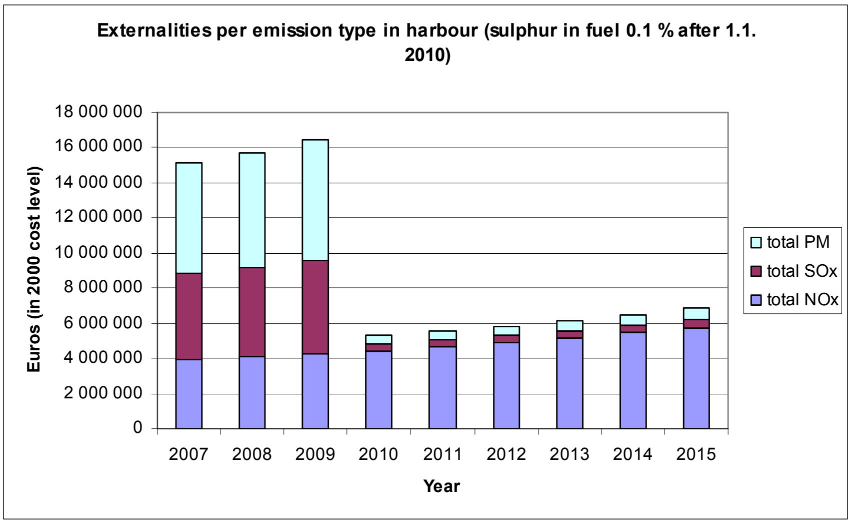

Figure 5.11 Emission externalities in harbour (excluding externalities of climate change)

Figure 5.12 demonstrates a scenario where the ships use the same fuel (1.0 S-%) at berth as at sea despite of the EU regulation. Comparing the result with Figure 5.11 shows that by radically decreasing the sulphur and PM emissions it is possible to diminish externalities.

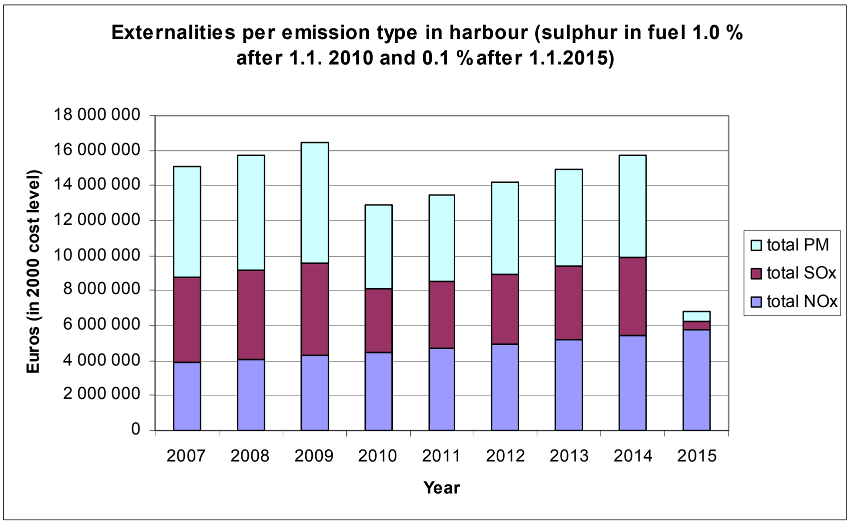

Figure 5.12 Harbour externalities per emission type, case: 1.0 % of sulphur in fuel in ports after 1.1.2010

The calculation of externalities in a port area is very sensitive to the share of the total emissions allocated to the ports of the GOF. In the calculations, the used shares are tabulated as in Table 4.9. The Entec 2002 result gives a 7 % share of ship-originated

SO_x emissions emitted in the port area (Figure 5.13). A radical increase of externalities will take place if the share is 10 % as shown in Figure 5.14. an increase of 3 % in the emissions share increases the harbour externalities by 14 %.

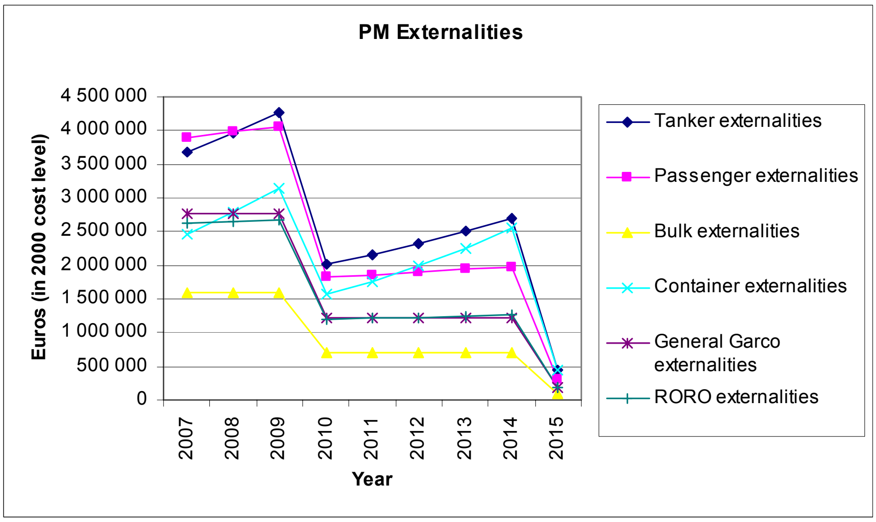

Figure 5.13 Sensitivity of spatial allocation (in case of PM externalities), share of in port emissions of SOx (and PM) 7 %

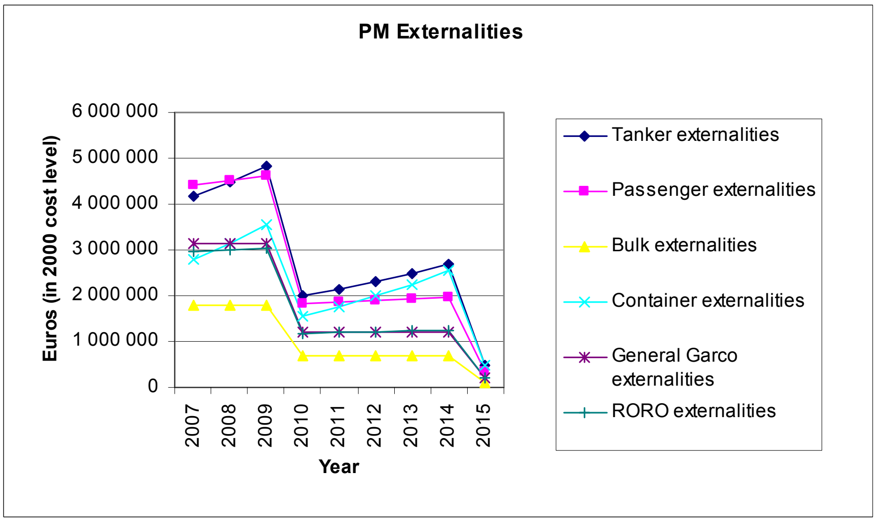

Figure 5.14 Sensitivity of spatial allocation (in case of PM externalities), share of in port emissions of SO_x (and PM) 10 %

5.1.5 Emission externalities near the coast and at open sea in the GOF

The near coast emissions form only 2 % of the total emissions (Table 4.9). Even though the near coast emissions have a higher unit cost (Table 3.1) it can be seen in Figure 5.15 that it is clearly the smallest of the three spatial categories.

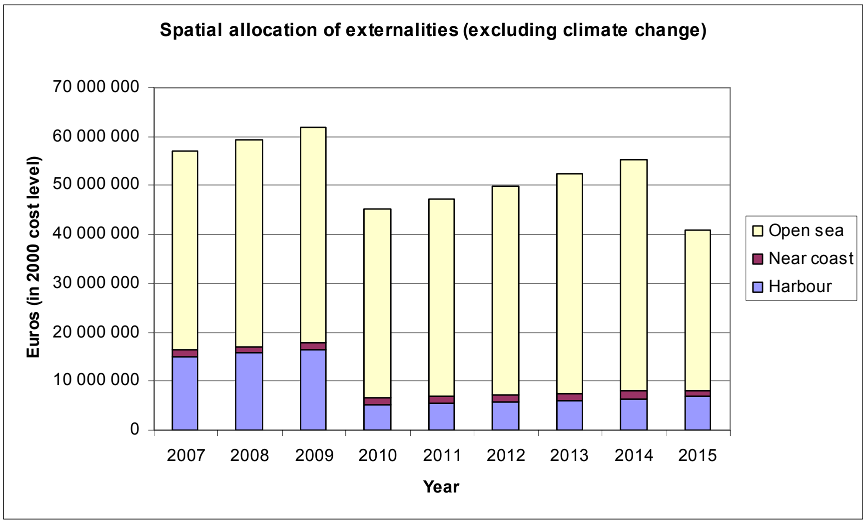

Figure 5.15 Total externalities (NO_x, SO_x, PM) spatially allocated

The open sea emission is the largest share of the three spatial categories. In Figure 5.15 we can see that regulating the in port emissions has better efficiency when compared to the open sea actions in Figure 5.16. It is mandatory to focus on the NO_x externalities after 2015 if the aim is to save in the total externalities. The CO_2 emission externalities are not included in this example.

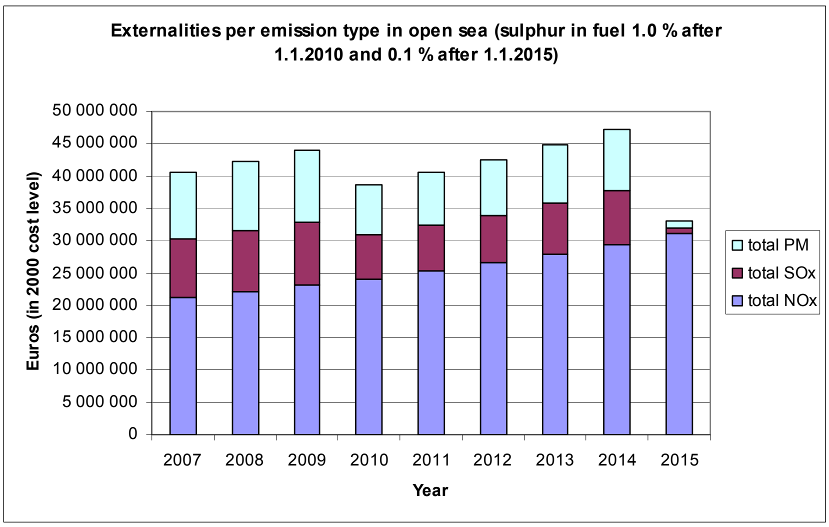

Figure 5.16 Externalities at open sea without the CO_2

6 TRANSIT TRAFFIC EXTERNALITIES: METHODS AND CALCULATIONS

The following chapter describes the basic assumptions and methodology used in the development of the externalities calculation algorithm for multimodal transport. The algorithm has been developed for the purpose of this study and it is capable of producing numerous scenarios. This study concentrates on four real examples.

6.1 Modelling of emissions and externalities of transport routes

We have calculated the marginal social costs based on the emission externalities of the car transport via Finland on four alternative routes for cars: arriving by vessels to the port of Turku, Hanko, Kotka or Hamina after which they are transported via road to the border of Russia (Vaalimaa) (Figure 6.1).

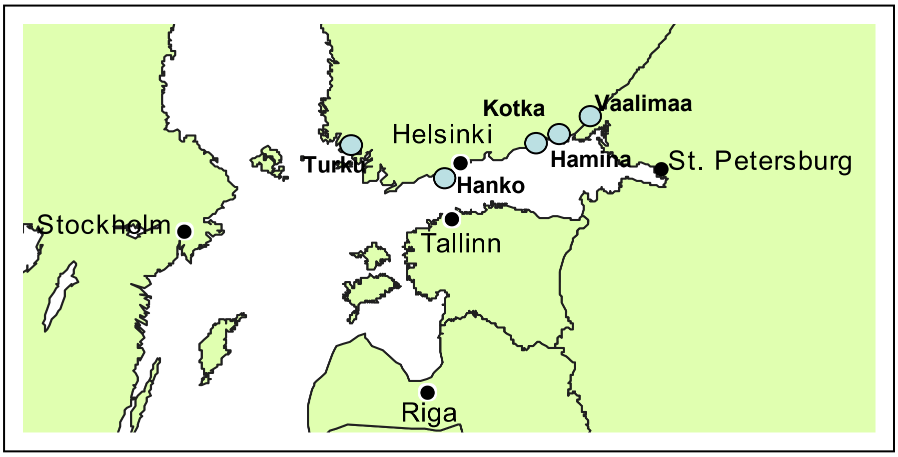

Figure 6.1 Area under study and ports of arrival

The emission externalities are calculated for the two transport modes (by sea and by road) and combined in each case. An average truck standard or the emission factors for the vehicle transport are unidentified. Therefore, the truck emissions are calculated based the on the Euro 1, 2 and 3 levels of truck emission factors (VTT, 2008). As a default value, the ship leaves the port empty and an empty truck comes from the border checkpoint to pick up the vehicles.

The calculation is performed by using MS Excel. The general assumptions used in the four case scenarios are presented in Table 6.1. The emissions per unit used for calculating the truck emissions in urban and rural areas are based on the Lipasto system (Mäkelä & al, 2008). The effects of one loaded ton on a truck to a certain emission compound can be calculated by dividing the division of the total truck emission and the empty truck emission with the maximum load capacity (40 tons). This value is used when calculating the initial unit emission per kilometre of a truck loaded with e.g. seven vehicles with 1.2 tons of mass each. The unit emissions for urban roads and rural roads presented in the Lipasto system are taken into account in the calculations separately.

The emission externalities are calculated with the following formulas:

1. $€_x$ = Externalities of compound X = $E_{totx,\ urban\ road}$ * $U_{x,\ urban\ area}$ + $E_{totx,\ rural\ road}$ * $U_{x,\ rural\ area}$ + $E_{totx,\ water}$ * $U_{x,\ water}$
2. $E_{totx,\ urban\ road}$ = Total urban road emissions of compound X = Ke_{urban} * $E_{x,\ urban}$ + Kf_{urban} * $Ev_{x,\ urban}$
3. $Etot_{x,\ rural\ road}$ = Total rural road emissions of compound X = Ke_{rural} * $E_{x,\ rural}$ + Kf_{rural} * $Ev_{x,\ rural}$
4. $E_{totx,\ water}$ = Total ship emissions of compound X = Emission factor for compound X [g/kWh] * P
5. U_x = Unit cost for compound X [€/t]
6. Ev = Unit emissions for truck with V vehicles as load [g/km] = E + (F - E) / 40 [t] * V * M
7. Ke_{urban} = Empty truck kilometres in an urban area [km] = N_{truck}*K_{urban}
8. Kf_{urban} = Full truck kilometres in an urban area [km] = N_{truck}*K_{urban}
9. Ke_{rural} = Empty truck kilometres in a rural area [km] = N_{truck}*(Ktot - K_{urban})
10. Kf_{rural} = Full truck kilometres in a rural area [km] = N_{truck}*(Ktot - K_{urban})
11. Ktot = Ke_{urban} + Kf_{urban} + Ke_{rural} + Kf_{rural}
12. T = Total ship voyage time = 2 * N_{ship} * K_{water} * V_{ship}
13. N_{ship} = Number of ship calls = Total amount of vehicles to be shipped / vehicle capacity of a ship
14. N_{truck} = Number of truck calls = Total amount of vehicles to be shipped / vehicle capacity of a truck
15. E_x = Unit emissions for an empty truck, compound X (source: VTT 2008) [g/km]
16. F_x = Unit emission for a truck with a full load of 40 tons, compound X [g/km]
17. V = Number of vehicles on a truck (e.g. 7)
18. M = Mass of a vehicle [t] (e.g. 1.2 t)
19. $Etot_x$ = Total emissions of compound X for truck traffic
20. P = Total pushing power [kWh] = 0,8 * installed engine power * T
21. V_{ship} = Velocity of a ship = service speed [km/h]
22. Urban = Share of urban road travelled by a truck or urban unit emission factors
23. Rural = Share of rural road travelled by a truck or rural unit emission factors

Exceptions include the soiling and the ship emissions that are derived from the fuel consumption:

24. $€_{soiling,\ road}$ = Ktot * soiling factor [€/vehicle-km]
25. $Etot_{CO2,\ water}$ = P * 200 g/kWh * 3.17 / 1000000
26. $Etot_{SOx,\ water}$ = P * 200 g/kWh * 2.002 / 1000000 (sulphur content of fuel 1.5 %)

6.2 Basic assumptions

The general assumptions are presented in Table 6.1, the emission and conversion factors in Table 6.2 and the unit costs in Table 3.2. There is no available data on the average amount of vehicles per truck or on the average mass of a vehicle. The total amount of transported vehicles via the Finnish ports to Russia was 339 620 in 2005 (Statistics of Finnish Customs 2008). Assumptions dependent on a ship are an example of attributes of a one car carrier.

Table 6.1 General assumptions

Variable	Value
Units/vehicles per truck	7
Unit/vehicle mass [t]	1.2
Total number of units/vehicles	339620
Car capacity of a ship	1530
Installed engine power of a car carrier [kW]	14480
Service speed [knot]	20
Sulphur content of fuel [%]	1.5
Engine load to reach service speed [%]	80

Table 6.2 Emission and conversion factors for ship emission estimation

Compound	Emission factor for a ship
SO_x	2.002 (conversion factor)
SO_x [t] = conversion factor*S*fuel consumption [t]	(Jalkanen & al, 2008)
S = sulphur content of fuel in %/100	
NO_x	14.0 g/kWh (Mäkelä & al, 2008)
$PM_{2.5}$	0.3 g/kWh (Mäkelä & al, 2008)
CO_2	3.17 (conversion factor)
CO_2 [t] = conversion factor*fuel consumption (heavy fuel oil) [t]	
CO	1.0 g/kWh (Mäkelä & al, 2008)
HC	0.4 g/kWh (Mäkelä & al, 2008)
CH_4	0.05 g/kWh (Mäkelä & al, 2008)
Fuel consumption	200 g/kWh (Alexandersson & al, 1993)

The distance between the starting point of the Finnish national waters and the ports as well as the distances from the ports to the border checkpoint are presented in Table 6.3.

Table 6.3 Distance table for truck and ship traffic kilometres

Port	Sea voyage (in Finnish national waters. Source: VTT 2008)	Land voyage (K_{tot} Source: Google maps)	Share of land voyage in urban area [km], (K_{urban} Source: Google maps)
Hamina	460	45.7	9.2
Hanko	210	320	35.7
Kotka	420	65.2	6.1
Turku	230	355	40.8

7 CAR TRANSIT: RESULTS AND SENSITIVITY ANALYSIS

In the results chapter, we present the total externalities for each scenario as the prime result. Other results are by-products of the externalities calculation. All results are analysed critically.

7.1 Results

Table 7.1, Figure 7.1 and Figure 7.2 present the summarized emission externalities for transporting 339 620 vehicles (the number of vehicles transported via Finland to Russia, in 2005, Statistics of Finnish Customs 2008) by ship to a Finnish port and after that by trucks to the Russian border checkpoint.

Hanko would be the best choice for transporting the vehicles if the Euro 3 level trucks are used. This is because of lower emissions of new trucks. If the trucks are classified as older Euro 1 level trucks, Kotka would be the best choice. This indicates that the truck emissions have a considerable effect on the externalities.

The Commission has calculated that the externalities charge for a Euro 4 level truck would be roughly in the range of 5 eurocents per kilometre. Calculated together with the results of Table 7.1, the emission costs (without CO_2) are some one eurocent per km for the Euro 3 level trucks and two eurocents for the Euro 1 level trucks. However, this example includes only the externalities of air pollution, not the congestion, noise or climate change. Despite of the fact that the cost levels are different and both calculations are rough estimations (algorithm and Commission) it can be concluded that the costs remain comparatively at the same level.

Table 7.1 Externalities for the transport of vehicles via the Finnish ports to Russia (in EUROS, year 2000 cost level)

Port of		SO_x	NO_x	$PM_{2.5}$	CO_2	CO	HC	soiling	SUM	SUM without CO_2
Hamina	Euro 1	229	35 971	122 311	143 359	50	107	835	302 863	159 504
	Euro 2	230	31 249	54 653	103 864	28	75	835	190 935	87 071
	Euro 3	232	20 701	37 441	106 599	22	59	835	165 889	59 290
	ship	209 821	354 973	107 488	1 295 736	128	3 909	N/A	1 972 055	676 320
	Euro 1 + ship	210 051	390 944	229 800	1 439 095	178	4 016		2 274 918	834 988
	Euro 2 + ship	210 052	386 222	162 141	1 399 600	156	3 984		2 162 991	762 555
	Euro 3 + ship	210 053	375 674	144 929	1 402 335	150	3 968		2 137 944	734 774
Hanko	Euro 1	1 126	208 984	490 383	956 097	198	584	3 366	1 660 738	704 641
	Euro 2	1 137	180 774	219 195	808 972	112	412	3 366	1 213 967	404 995
	Euro 3	1 147	119 623	150 006	830 285	87	324	3 366	1 104 838	274 553
	ship	95 788	162 053	49 071	591 532	58	1 784	N/A	900 286	308 755
	Euro 1 + ship	96 914	371 037	539 454	1 547 628	257	2 368		2 561 024	1 010 030
	Euro 2 + ship	96 925	342 827	268 266	1 400 503	170	2 197		2 114 253	710 384
	Euro 3 + ship	96 935	281 676	199 077	1 421 816	145	2 109		2 005 124	579 941
Kotka	Euro 1	210	40 827	84 953	192 854	34	112	584	319 575	126 721
	Euro 2	212	35 278	37 978	168 167	19	79	584	242 319	74 152
	Euro 3	214	23 338	25 979	172 598	15	62	584	222 791	50 193
	ship	191 576	324 106	98 142	1 183 063	117	3 569	N/A	1 800 572	617 509
	Euro 1 + ship	191 786	364 933	183 095	1 375 917	151	3 681		2 120 148	743 646
	Euro 2 + ship	191 788	359 384	136 120	1 351 230	136	3 648		2 042 891	691 076
	Euro 3 + ship	191 790	347 444	124 121	1 355 661	132	3 631		2 023 363	667 118
Turku	Euro 1	1 269	233 626	559 254	1 062 656	226	655	3 837	1 861 524	798 868
	Euro 2	1 281	202 129	249 974	894 053	128	462	3 837	1 351 864	457 811
	Euro 3	1 292	133 761	171 081	917 607	99	364	3 837	1 228 041	310 434
	ship	104 911	177 487	53 744	647 868	64	1 954	N/A	986 028	338 160
	Euro 1 + ship	106 180	411 113	612 998	1 710 524	290	2 609		2 847 552	1 133 190
	Euro 2 + ship	106 192	379 615	303 718	1 541 921	191	2 417		2 337 891	792 133
	Euro 3 + ship	106 203	311 248	224 825	1 565 475	163	2 318		2 214 069	644 756

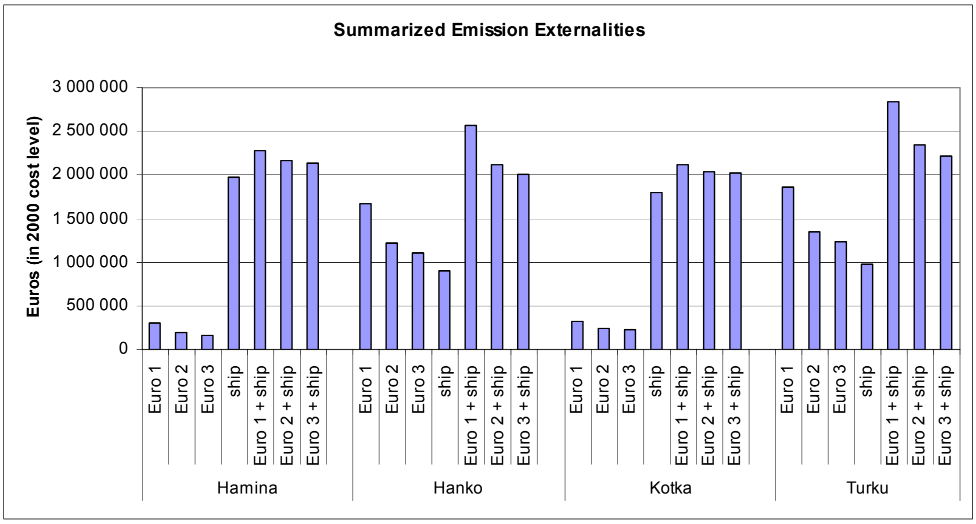

Figure 7.1 Graphical presentation of the values of Table 7.1.

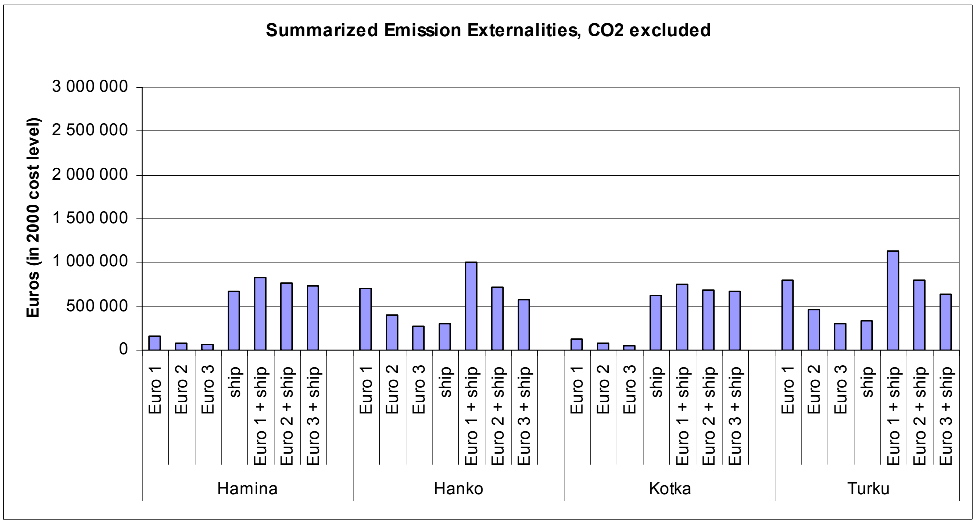

Figure 7.2 Graphical presentation of values in Table 7.1, CO_2 excluded.

7.2 Sensitivity analysis

We also studied some scenarios to identify the potential effect of a certain variable. Identifying the crucial variables might reveal important information about relevant actors in order to minimize the external costs of the vehicle transit transport.

Firstly, the scenario was modelled by older and more polluting trucks, e.g. the Euro 1 level trucks. As a result, the externalities of all the modelled routes changed and their ranking changed as well. Now, the Kotka route had the least externalities after which the routes via Hamina, Hanko and Turku were ranked. Hence, the algorithm is very sensitive to the age and pollution rate of trucks.

Secondly, if the number of cars increases from 1 500 to 2 000 on board of a ship, it will result in an increase of the externalities from 1 836 583 Euros to 1 377 437 Euros. This means saved externalities of 459 145 Euros. In summary, the shipping kilometres and emission externalities per car can be cut to half by doubling the number of vehicles onboard.

Thirdly, the decrease of the sulphur content of the bunker fuel will lower the emission externalities substantially. For example, by decreasing the sulphur content of bunker fuel to 0,001 % of the total amount in the case of Turku, a potential economic gain of 191 576 Euros becomes attainable.

Finally, we discovered that a linear relationship exists between the urban road kilometres and the emission externalities: the more urban road kilometres, the more emission externalities. In this scenario, the truck-generated emission externalities doubled when the kilometres driven in an urban area rose fourfold.

In the border areas, long queues of heavily loaded lorries might occur (up to 80 kilometers), creating serious safety and environmental problems (Loeb & Clarke, 2007). This fact is not taken into account when calculating the emissions of trucks. Including this fact to the calculations will increase the total emissions of trucks thus changing the relation of the emissions between the different transport modes. However, this does not affect the comparability of the results between the transit routes because the same effect applies to each route.

7.2.1 Total emissions

The truck and ship emissions are presented in Table 7.2 and the corresponding graphical presentations are introduced in Appendix 2. These results show that despite of the much higher emission amounts of ship transport the total externalities are not linearly dependent on the emitted tons of the pollutant. Spatial differences in the costs of the emitted ton are in a crucial role in the calculation of the total externalities.

Table 7.2 Emissions for vehicle transport via Finnish ports to Russia [tons]

Port of		SO_x	NO_x	$PM_{2.5}$	CO_2	CO	HC	CH_4	fuel consumption [t]
Hamina	Euro 1	0.01	16.39	0.59	1283.48	2.03	0.97	0.03	408.18
	Euro 2	0.01	14.42	0.26	1303.82	1.14	0.66	0.03	414.09
	Euro 3	0.01	9.58	0.18	1338.49	0.88	0.53	0.02	425.56
	ship	383.59	894.14	19.16	40491.74	63.87	25.55	3.19	12773.42
	Euro 1 + ship	383.60	910.53	19.75	41775.23	65.89	26.51	3.23	13181.60
Hanko	Euro 1	0.05	63.62	2.27	4980.47	7.86	3.75	0.14	1583.90
	Euro 2	0.05	55.96	1.02	5059.41	4.43	2.57	0.10	1606.87
	Euro 3	0.05	37.19	0.70	5193.93	3.43	2.05	0.08	1651.35
	ship	175.12	408.19	8.75	18485.36	29.16	11.66	1.46	5831.34
	Euro 1 + ship	175.16	471.81	11.02	23465.84	37.02	15.41	1.59	7415.25
Kotka	Euro 1	0.01	10.87	0.39	851.01	1.34	0.64	0.02	270.64
	Euro 2	0.01	9.56	0.17	864.49	0.76	0.44	0.02	274.56
	Euro 3	0.01	6.35	0.12	887.48	0.59	0.35	0.01	282.16
	ship	350.23	816.39	17.49	36970.72	58.31	23.33	2.92	11662.69
	Euro 1 + ship	350.24	827.26	17.88	37821.73	59.66	23.97	2.94	11933.33
Turku	Euro 1	0.06	72.71	2.60	5691.97	8.98	4.28	0.16	1810.17
	Euro 2	0.06	63.96	1.16	5782.18	5.06	2.94	0.11	1836.42
	Euro 3	0.06	42.50	0.80	5935.92	3.92	2.35	0.09	1887.25
	ship	191.79	447.07	9.58	20245.87	31.93	12.77	1.60	6386.71
	Euro 1 + ship	191.85	519.78	12.18	25937.84	40.91	17.06	1.75	8196.88

7.2.2 Effect of spatial allocation of emissions

One of the most important variables in the externalities calculation is the location of the emitted emissions. The emission externalities are tabulated in Table 3.1. Especially in the case of particle emissions, the effect of population density is affected by the PM emissions. CO_2 is the only compound whose externality is not dependent on the location of the emission.

The developed calculation algorithm for the car transit takes into account the urban road conditions in two ways. Firstly, it considers the specific emission factors for a truck which can change depending on the road type (VTT, 2008). Secondly, the externalities cost value is taken into consideration (Table 3.2).

The case of the urban road share has been studied with the algorithm by giving constant values for the other variables besides the urban road distance. This simulation is presented in Figure 7.3 and it is produced with the following constants: a 100 km trip distance, 7 vehicles in one truck, a mass of 1.2 tons per vehicle and a total of 339 620 vehicles. The result is that the urban road share is a very sensitive variable. With minor changes in the urban road share, the algorithm shows considerable changes in the total externalities originating from trucks.

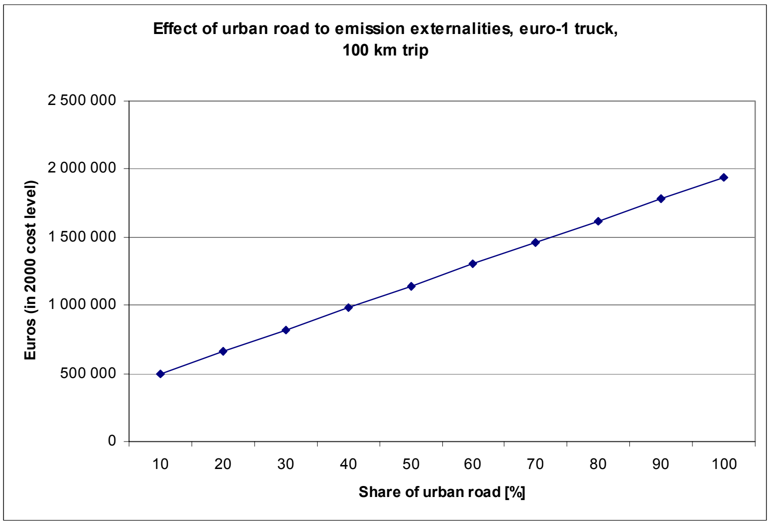

Figure 7.3 Spatial targeting of emissions, share of urban road of the total trip length

7.2.3 Vehicles per truck

The effect of the load rate of a truck was studied and the results are presented in Figure 7.4. The effect is exponential and considerably high. This is stemming from the fact that the more vehicles you can carry simultaneously the less trips you have to make to pick up the vehicles from the harbour . The constants used to produce the data for Figure 7.4 are the same as for the case of Turku (Table 6.3).

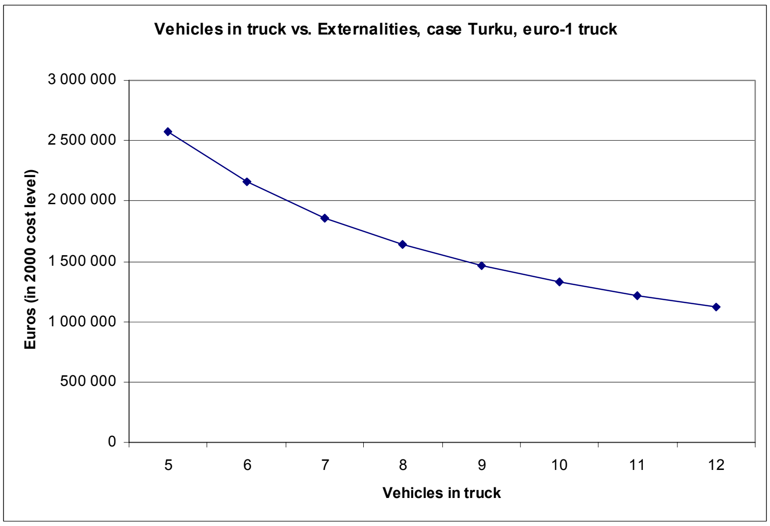

Figure 7.4 The effect of load rate of a truck on the total externalities

7.2.4 The amount of vehicles in a ship

Similarly, as in the case of a truck, the amount of vehicles per car carrier has strong effects on the externalities. The example car carrier has a capacity of 1530 vehicles. With a minor increase in the vehicle capacity, the externalities can be decreased considerably.

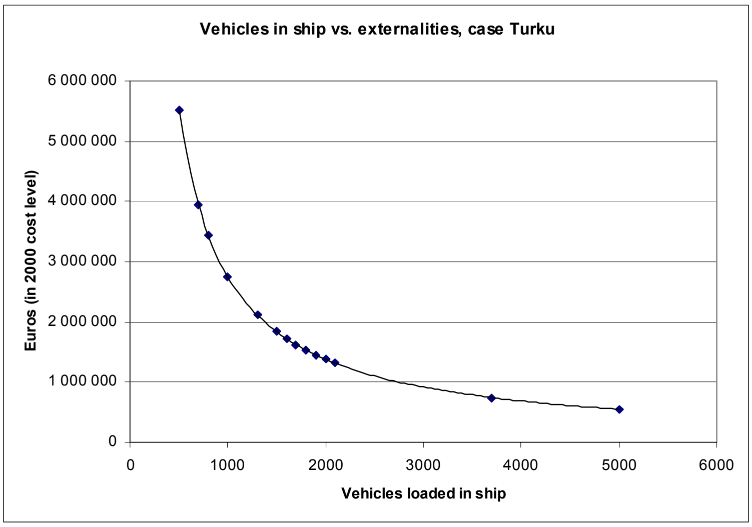

Figure 7.5 The effect of the amount of vehicles in a ship on the emission externalities

7.2.5 The effect of fuel quality on externalities

The international regulations are stricter in the Baltic Sea region when compared to global provisions. The vessels sailing in the Baltic SECA area must use fuel with sulphur content less than 1.5 % m/m. Figure 7.6 shows how the sulphur content affects the total externalities. The effect is surprisingly small. This is due to the spatial allocation of the emissions which does not take the vessel berth time into account. Another important factor missing is the fact that when decreasing the sulphur content the PM emissions decrease simultaneously. The PM calculation in this case is based on the emission factor of 0.3 g/kWh (Table 6.2).

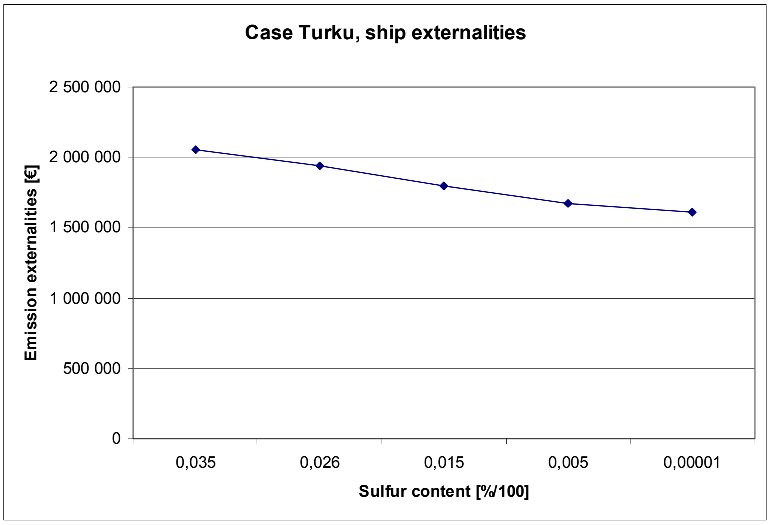

Figure 7.6 The effect of fuel quality on the externalities

8 CONCLUSIONS AND DISCUSSION

In the following chapter, we present the conclusions for both study parts: the ship-originated emission externalities in the Gulf of Finland and the externalities from the passenger car transit via Finland to Russia.

8.1 Modelling of emissions and externalities of the GOF shipping

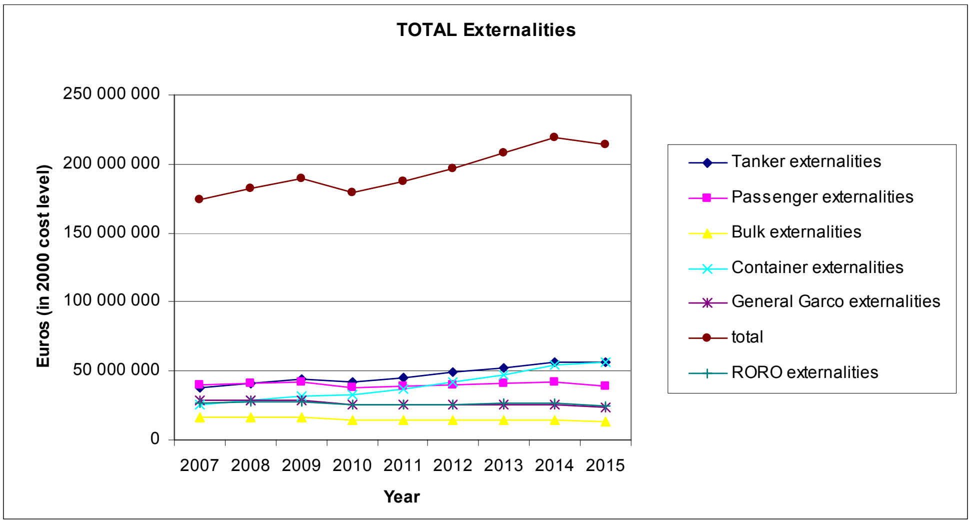

Figure 8.1 The total externalities of shipping in the Gulf of Finland, including the externalities of the climate change (CO_2)

The externalities were 175 million Euros in 2007 and 214 million Euros in 2015 (Table 5.4) leading to the externality growth of 22 %. There are upcoming provisions that will reduce the sulphur emissions and thus simultaneously the particle emissions in 2010 and 2015. However, such decreases of the externalities will not be permanent because the traffic growth will compensate the savings (Figure 8.1). In this calculation, the CO_2, NO_x, SO_x and PM emissions are taken into account as well as the six major ship types: bulk, passenger, tanker, container, general cargo and Ro-Ro vessels.

Table 8.1 The total externalities without CO_2 in Euros (in 2000 cost level)

Ship types Year	Tanker	Passenger	Bulk	Container	General Cargo	RORO	total
2007	12 311 079	13 061 055	5 338 275	8 225 074	9 266 863	8 755 146	56 957 492
2008	13 241 796	13 330 113	5 338 275	9 302 559	9 266 863	8 874 001	59 353 607
2009	14 242 876	13 604 713	5 338 275	10 521 194	9 266 863	8 995 678	61 969 599
2010	10 675 897	9 676 111	3 720 119	8 292 463	6 457 860	6 364 766	45 187 216
2011	11 482 995	9 875 439	3 720 119	9 378 775	6 457 860	6 458 578	47 373 766
2012	12 351 109	10 078 873	3 720 119	10 607 395	6 457 860	6 555 502	49 770 859
2013	13 284 853	10 286 498	3 720 119	11 996 964	6 457 860	6 655 835	52 402 128
2014	14 289 188	10 498 399	3 720 119	13 568 566	6 457 860	6 759 906	55 294 039
2015	10 761 835	7 502 511	2 604 863	10 745 448	4 521 855	4 848 168	40 984 679

CO_2 constitutes the biggest portion when examining the cause of externalities. It is likely that the portion is overestimated when compared to the externalities produced by the other compounds. If CO_2 is neglected by extracting the CO_2 externalities from the calculation we get the total externalities of 57 million Euros in 2007. After eight years, the externalities would be 28 % lower, 41 million Euros (Table 8.1). This result shows the efficiency of reducing the sulphur content of marine fuels in open sea and in a port. The effect of the provisions on the externalities is not caught up before 2015 (Figure 8.2).

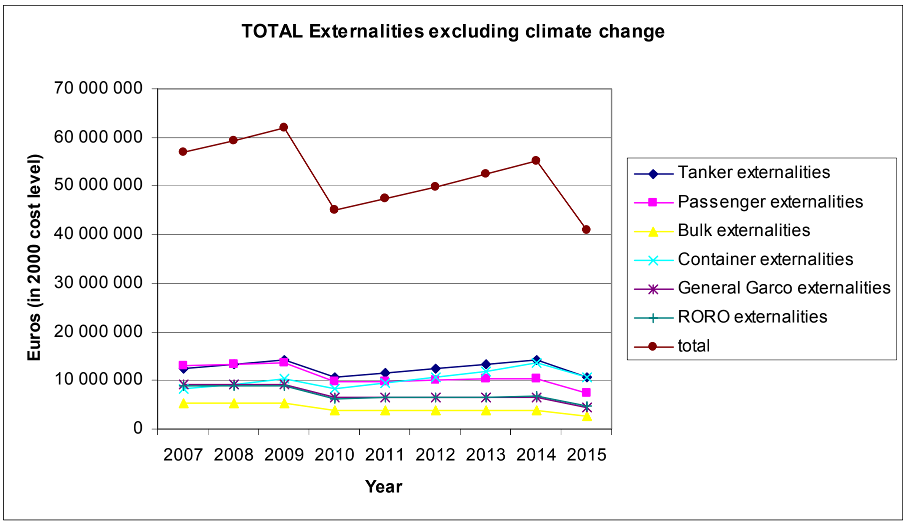

Figure 8.2 Total externalities of shipping in the Gulf of Finland, excluding climate change (CO_2)

Most of the ship-originated externalities are produced by the six major ship classes shown in Table 8.2. These ships represent almost 88 % of the total NO_x emissions in the Gulf of Finland. Due to the dramatic increase in the container transport to and from the GOF ports (especially the Russian ports), the externalities produced by the container vessels are expected to reach the lead in 2015 despite of a considerable increase in the tanker traffic as well.

Table 8.2 Traffic growth and the share of externalities per ship type in 2007 (Gulf of Finland)

Vessel type	Traffic growth per annum [%]	Share of externalities in 2007
Passenger vessels (including cruisers and ROPAX vessels)	2.06	23 %
Tankers	7.56	22 %
General cargo vessels	0	14 %
Ro-Ro vessels	1.24	15 %
Container vessels	13.1	14 %
Bulk vessels	0	9 %

Table 8.3 Share of externalities per ship type in 2015 (Gulf of Finland)

Vessel type	Share of externalities in 2015
Passenger vessels (including cruisers and ROPAX vessels)	18 %
Tankers	26 %
General cargo vessels	11 %
Ro-Ro vessels	12 %
Container vessels	26 %
Bulk vessels	6 %

The NO_x externalities will not continue to increase with the same rate after the year 2015. Despite of the growing trend shown in Figure 5.5, the renewal of ships and the Tier 3 provisions by MARPOL Annex VI will force the NO_x emissions to decrease in the future. Also, the other provisions concerning sulphur (and particles emissions) in marine fuels will affect the total externalities. Especially after 2010, the 0.1 % sulphur limit in the EU ports and the 0.1 % sulphur limit in the SECA after 1 January 2015 will decrease the externalities so that the CO_2 and NO_x emissions should be taken into account in any further actions to gain efficient savings.

After regulating the SO_x and PM emissions there is still potential left for the reductions of shipborne externalities. Affecting the CO_2 and NO_x emission externalities is not possible by reducing near coast or port emissions. To achieve savings in those externalities, strict actions to lower the overall CO_2 and NO_x emissions are needed.

The externalities calculation has several sensitive variables. The unit cost of the emitted ton of a compound (Table 3.1) is a crucial factor. Furthermore, this leads to another factor which is the division of the total emissions into spatial classes shown in Table 4.9. It is understandable that incorrect spatial allocation of the PM emissions will lead to considerable errors because of the very high unit cost difference in the allocation of the PM emissions.

We can conclude that estimating the ship-generated air emission externalities reveals valuable data about the environmental impact of shipping. Furthermore, the approach of social marginal costs is useful in the future scenario estimates. This method is valuable when estimating the effect of technical development or the effect of regulations.

The disadvantage of the method used in this study is that a very accurate emission data would be needed for proper estimation of the externalities. At best, the ship-originated emissions are estimated as well as the dispersion of the emissions. Combining the dispersion data (emission concentrations) with a Geographical Information Systems (GIS) data of population density would give much more accurate results compared to the use of spatial allocation as in Table 3.1. Updates for the unit costs of emissions are needed for more accurate calculation of externalities.

8.2 Modelling of emissions and externalities of transit traffic

The public discourse on the passenger car transit via Finland to Russia with its effects is continuous in Finland. In this article, we have compared four transportation routes (from the ports of Turku, Hanko, Kotka and Hamina) by using the marginal social cost approach based on the externalities of air pollution from sea and road traffic. We discovered that the emissions externalities are on the lowest level when the passenger cars are transported via Hanko. This can be considered somewhat surprising as the ports of Kotka and Hamina are located closer to the Russian border. The cause for this inconsistence is the relatively high ship emission level in these areas.

The emissions from vessels are relatively high when compared to the emissions from trucks. This is due to mainly two reasons: the sulphur content in the vessel fuel is greater and the vessels might travel only part-loaded, e.g. the vessels could take much more cargo (in tons), but they do not have any excess space for passenger cars.

In addition, we discovered that the results are affected by the sulphur content of marine fuel and the urban road share on the journey made. Increasing the number of cars on the vessels and decreasing the sulphur content of the fuel as well as the urban road share all reduce the emission externalities substantially.

This study also introduces the weaknesses on the calculation system: firstly, the system takes into account only some of the externalities and consequently e.g. congestions on roads, road building, sea and road accidents, noise, dust, and their effect on wildlife and scenery are not observed.

Secondly, the environmental effects of port traffic were not observed. The external costs of each port vary according to the used machines, and the ports effect on the surrounding dwelling places.

The Russian trucks are typically using Russian fuel which may include an elevated content of sulphur. Hence, the advantage of road traffic compared to sea voyage is overestimated, at least in this case.

The conclusion is thus that the calculation of the marginal social costs based on the air emission externalities should not be regarded as a ready-made calculation system. The system is clearly in the need of some improvement but it can already be considered as a potential tool for political decision making.

9 REFERENCES

Alexandersson, A., E. Flodström, R. Öberg & P. Stålberg (1993). Exhaust Gas Emissions from Sea Transportation. MariTerm AB, Swedish Transport Research Board. TFB report nro 1.

Bickel P., R. Friedrich, H. Link, L. Stewart & C. Nash (2006). Introducing Environmental Externalities into Transport Pricing: Measurement and Implications. *Transport Reviews, vol. 26, nro 4*, 389–415, July 2006.

CEC (Commission of the European Communities) (1995). Towards Fair and efficient Pricing in Transport, Policy Options for Internalising the External Cost of Transport in the European Union. *Green Paper*. COM (95) 691 final, 20 December 1995

ENTEC (2002). European Commission Quantification of emissions from ships associated with ship movements between ports in the European Community. Chapters 1 and 2, Entec UK Limited. Final Report. July 2002

ENTEC (2005a). European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market Based Instruments. Task 1 – Preliminary Assignment of Ship Emissions to European Countries. Entec UK Limited. Final Report. August 2005.

ExternE (2008). 27.11.2008. ExternE – Externalities of Energy, A Research Project of the Eropean Commission.
<*http://www.externe.info/*>

FMA (Finnish Maritime Administration) (2002). 27.11.2008. Vesiliikenteen aluskohtaisten päästökustannusten yksikköarvot, Päivitys 2002 (Vessel specific unit costs of emissions, Update 2002, in Finnish).
<*http://veps.fma.fi/portal/page/portal/fma_fi/tietopalvelut/julkaisut/julkaisusarjat/2002/aluskoht_paastokust_paivitys.pdf*>

FMA (Finnish Maritime Administration) (2008a). Suomen konttikuljetukset merits. (Finnish Sea transport of Containers, in Finnish). *Merenkulkulaitoksen julkaisuja 4/2008,* Helsinki. 2008.

FMA (Finnish Maritime Administration) (2008b). Satamien ulkomaan alusliikenne alustyypeittäin vuosina 1981 – 2007. 3.9.2008.
<*http://www.fma.fi/palvelut/tilastot/mlt/mlt_al_alustyypeittain.htm*>

Hietala (2008). 2.10.2008. E-mail from Meri Hietala/Finland's environmental administration to Jenni Kuronen/Centre for Maritime Studies. Öljykuljetustietoja (Oil transport information, in Finnish). Personal communication.

IMO (International Maritime Organization) (2008). International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78). ANNEX VI: Prevention of Air Pollution from Ships.

Jalkanen J-P., M. Hongisto & A. Brink (2008). 3.8.2008. A First-Guess Estimate of SO_x Emissions and Deposition Caused by the Ship Traffic in the Baltic Sea Area during March 1st 2006 – February 28th 2007 *<http://www.shipnodeff.org/images/stories/julkaisut/sox_emissions_and_deposition_isbn978-951-53-3037-6.pdf>*

Kuronen J., R. Helminen, A. Lehikoinen & U. Tapaninen (2008). Maritime transportation in the Gulf of Finland in 2007 and in 2015. *Publications from the Centre of Maritime Studies, university of Turku, A45*. Kopiojyvä Oy, Kouvola. 2008.

Lloyd's Register Fairplay, Moffatt & Nichol, AIS Live & Fairplay (2007). North Sea Baltic Hub – Market Analysis, Scenario and port action points.

Loeb, P.D. & W.A. Clarke (2007). The determinants of truck accidents. *Transportation Research* Part E 43 (4), 442–452.

MINTC (Ministry of Transport and Communications) (2003). 26.8.2008. Liikenteen päästökustannukset Päivitys ja yhteenveto. (External costs of traffic, in Finnish) Report B 29/2003, Helsinki. *<http://alk.tiehallinto.fi/julkaisut/pdf/liikenteenhallinta/yleistietoa/liikennevaylahankkeiden_arvioinnin_yleisohje_2003.pdf>*

Mäkelä K., T. Järvi, A. Tuominen & E. Pääkkönen. (2008). 5.6.2008. Suomen vesiliikenteen päästöjen laskentajärjestelmä MEERI 2006. (Calculation system for emissions of Finnish sea traffic, in Finnish) *<http://lipasto.vtt.fi/lipasto/meeri/meeri2006raportti.pdf>*

Nash C. & B. Matthews (2005). Measuring the Marginal Cost of Transport. *Research in Transportation Economics,* vol. 14. 2005.

Ojala, L. (1995). Logistics Management in Finnish Foreign Trade Transport. *Turku School of Economics and Business Administration Publications*, A3. Turku.

Ollus S.-E. & H. Simola (2006). Russia in the Finnish economy. *Sitra reports* 66. Sitra, Helsinki.

Ruutikainen P., T. Inkinen & U. Tapaninen, (2008). Transit of High-Value Goods via Finland to Russia. In: O-P. Hilmola (ed.): Fourth International Railway Logistics Seminar: - Co-operation among Transportation Modes in Northern Europe. *Lappeenranta University of Technology, Faculty of Technology Management, Research report* 200: 89 – 206.

Sergeeva, R. (2007). Ulkomaiset valmistajat Venäjän henkilöautomarkkinoilla. (Foreign manufacturers in Russian automobile markets, in Finnish). *Northern Dimension Research Centre Publications* 41. Lappeenranta University of Technology, Lappeenranta.

Statistics of Finnish Customs (2008). Finnish Trade Statistics. 27.4.2008 <*http://www.tulli.fi/en/03_Foreign_trade_statistics/06_statistics/01_timeseries/index.jsp*>

Stipa T., J-P. Jalkanen, M. Hongisto, J. Kalli, A. Brink (2007). 26.11.2008. Emissions of NO_x from Baltic Shipping and First Estimates of their effects on air quality and eutrophication of the Baltic Sea. <*http://www.shipnodeff.org/images/stories/nox_emissions_baltic_isbn978-951-53-3028-4.pdf*>

Tuominen, A. & V. Himanen (2007). Assessing the interaction between transport policy targets and policy implementation – A Finnish case study. *Transport Policy* 14 (5), 388–398.

CEC (Comission of the European Communities) (2008). Communication from the Commission. COM(2008)435 final. <*http://ec.europa.eu/transport/greening/doc/costs/2008_07_greening_transport_cost_communication_en.pdf*>

United Nations (2005). 27.11.2008. Regional Shipping and Port Development Strategies (Container Traffic Forecast). <*http://www.unescap.org/ttdw/Publications/TFS_pubs/pub_2398/pub_2398_fulltext.pdf*>

VTT (2008). 27.11.2008. Unit emissions for trucks in Finland, Lipasto. <*http://lipasto.vtt.fi/yksikkopaastot/tavaraliikenne_tieliikenne.htm*>

Wahlström, J., N. Karvosenoja, & P. Porvari (2006). 21.8.2006. Ship emissions and technical emission reduction potential in the Northern Baltic Sea. Helsinki, Finnish Environment Institute. *Reports of Finnish Environment Institute,* 2006. 70 p. <*http://www.ymparisto.fi/download.asp?contentid=55273&lan=en*>

10 APPENDIX 1

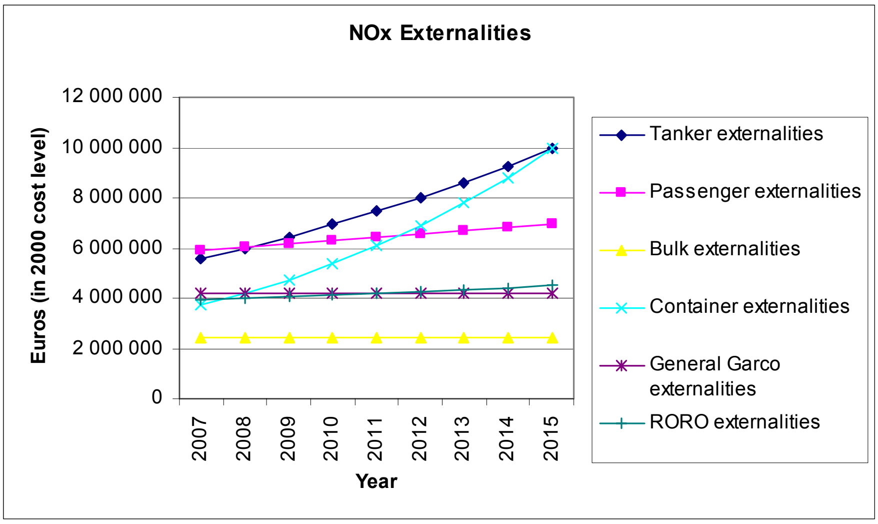

Figure 10.1 NO_x externalities per year in the Gulf of Finland

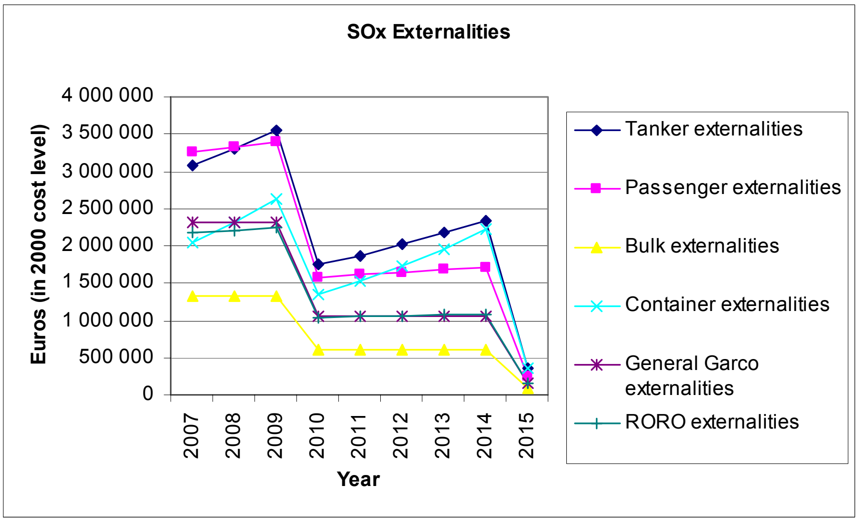

Figure 10.2 SO_x externalities per year in the Gulf of Finland, 0.1 %-S after 1 Jan .2010 in ports

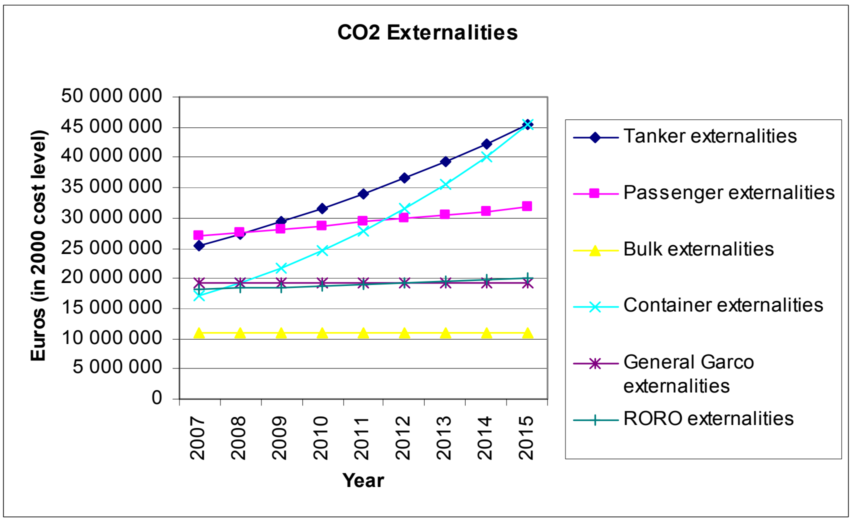

Figure 10.3 CO_2 externalities per year in the Gulf of Finland

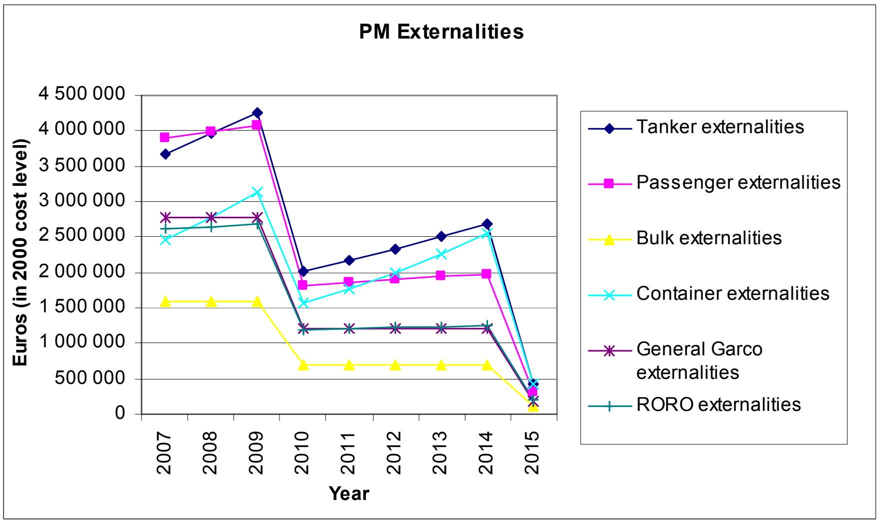

Figure 10.4 PM externalities per year in the Gulf of Finland, 0.1 %-S after 1 Jan 2010 in ports

11 APPENDIX 2

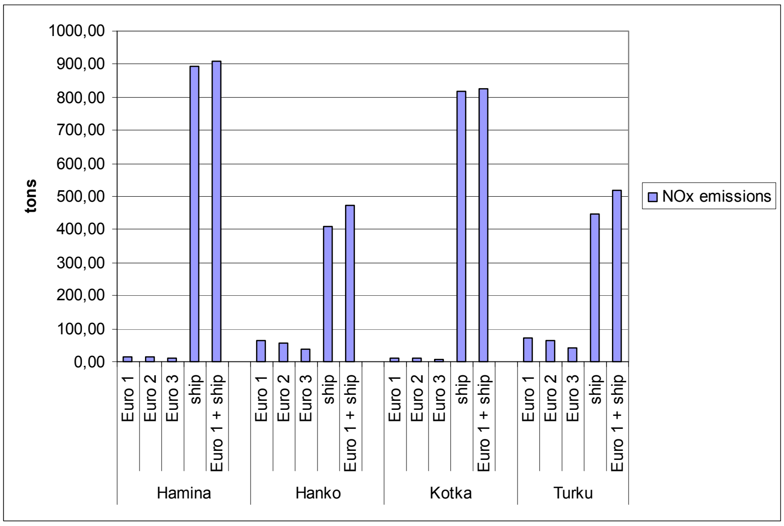

Figure 11.1 NO_x for each studied case

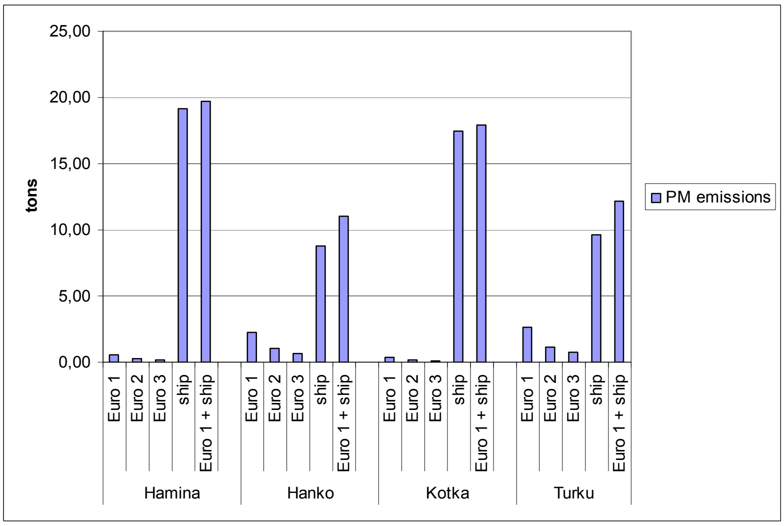

Figure 11.2 PM emissions for each studied case

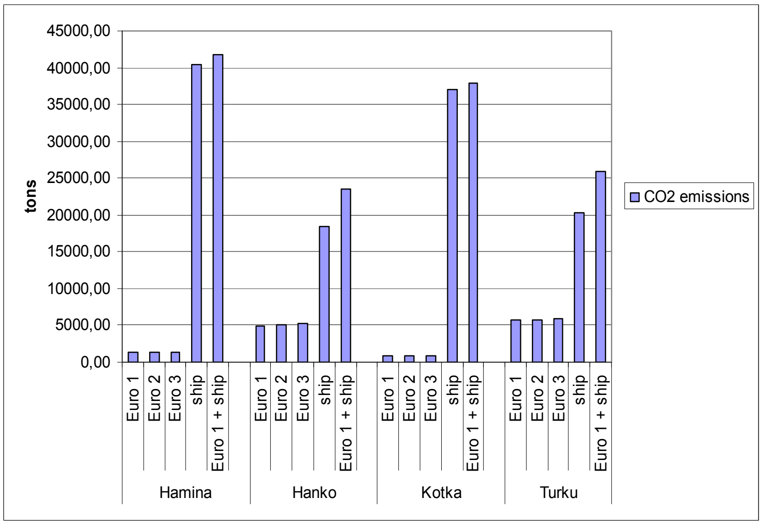

Figure 11.3 CO_2 emissions for each studied case

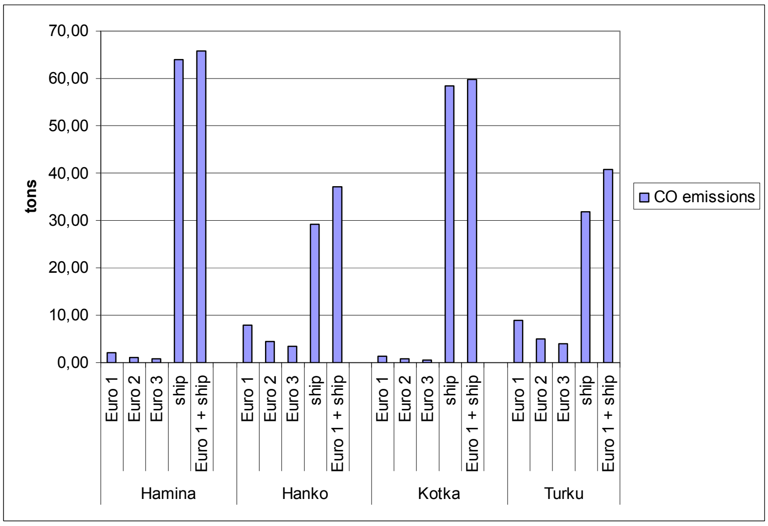

Figure 11.4 CO emissions for each studied case

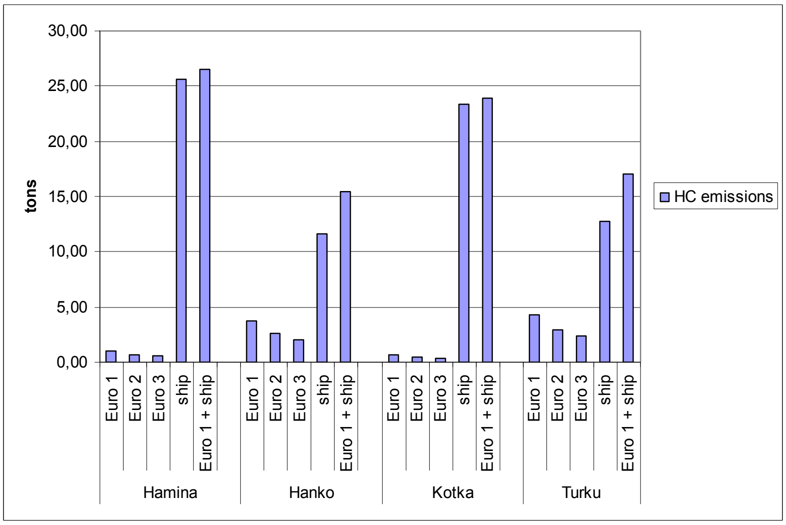

Figure 11.5 HC emissions for each studied case

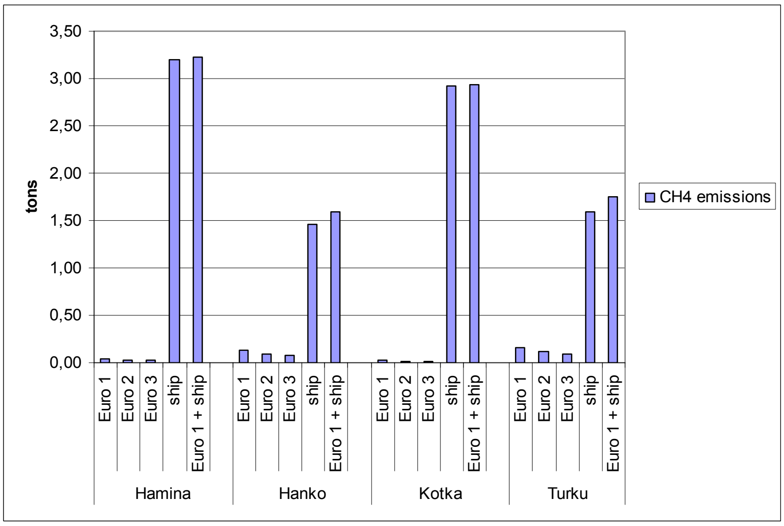

Figure 11.6 CH4 emissions for each studied case

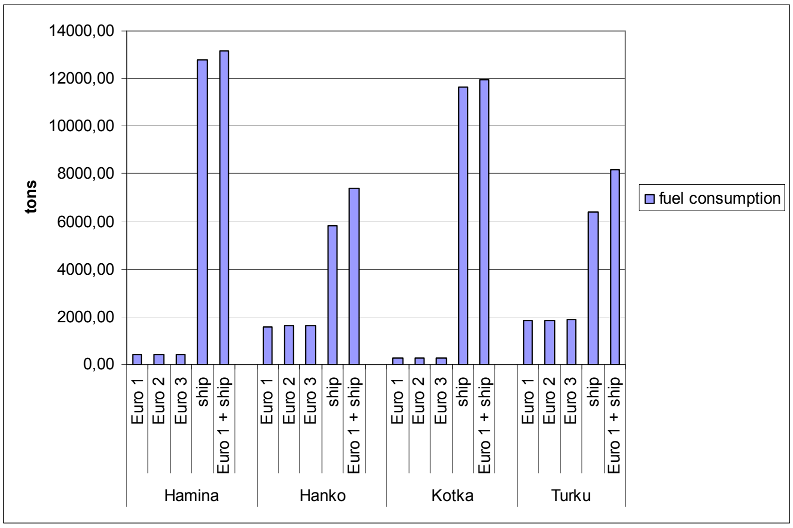

Figure 11.7 Fuel consumption for each studied case

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