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QUANTIFYING THE FINANCIAL IMPACT OF DIESEL ENGINE EXHAUST GAS EMISSIONS OF SMALL GENERAL CARGO AND BULK VESSELS

Master´s Thesis
in Logistics

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CDM	Clean Development Mechanism
CER	Certified Emissions Reduction
CO_2	Carbon Dioxide
DWCC	Deadweight Cargo Capacity
ECA	Emission Control Area
ECX	European Climate Exchange
ERU	Emission Reduction Unit
EUA	European Union Allowance
EU ETS	European Union Emissions Trading Scheme
GHG	Greenhouse Gas
GT	Gross Tonnage
HFO	Heavy Fuel Oil
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JI	Joint Implementation
MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MFO	Medium Fuel Oil
MGO	Marine Gas Oil
NAP	National Allocation Plan
NO_x	Nitrogen Oxides
NTUA	National Technical University of Athens
OTC	Over-the-counter
SECA	Sulphur Emission Control Area
SO_2	Sulphur Dioxide
UNCLOS	United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change

1 INTRODUCTION

1.1 Background information for this study

Pollutions have an effect in all our lives whether we are the ones emitting them or not. Due to the nature of different pollutants, they can affect people, our climate and the earth itself from vast expanse or for a prolonged time, and occasionally both conditions are met at the same time. Pollutions do not recognize national boundaries or the nationality of the emitter. The impacts that some emissions have, can be categorize into three types: local, regional and global pollutants. The difference is the distance which they travel in the air. (Tietenberg 2000, 389.)

Thus, the very nature of pollution makes it joint responsibility for everybody. Pollution and its' causes are, however, a very difficult subject for the international groups and conventions. The juxtaposition of developed nations and underdeveloped nations hinders progress in international negotiations. The latest example is from December 2009; the United Nations Framework Convention on Climate Change (UNFCCC) held in Copenhagen, which is also known as the Copenhagen Summit. The aim of the Copenhagen Summit was to create a successor for the Kyoto Protocol that expires in a couple of years. High hopes were placed for the convention beforehand, but the convention concluded without a legally binding treaty. The only concrete result of the Copenhagen Summit has been the blame game between nations and groups that ensued. Without a binding international environment treaty, it is very likely that the EU – who is leading the way in global climate change fight – will move forward on its' own accord.

In this thesis I will examine the current environmental discussion and regulations in relation to international maritime industry, especially in the Northern Europe. As Psaraftis and Kontovas (2009a, 1) point out in their study: "*Carbon dioxide (CO_2) emissions from commercial shipping are currently unregulated"*. However, the maritime industry emissions have been under discussion in several different institutions, such as the International Maritime Organization (hereafter referred to as IMO) and the European Union. The European Union has made a statement that it will include shipping into the European Union Emissions Trading Scheme if IMO does not come up with a solution in the time period given by the EU.

In light of this, the emissions trading scheme and current maritime industry regulation are reviewed and their impacts on shipping industry are assessed. I will attempt to evaluate the possible financial implications of including maritime industry into Emissions Trading Scheme. The evaluations of financial impacts are done from ship owner's perspective.

In April 2010, Lloyd's ship register contained roughly 5,750 ships that are categorized as dry bulk or general cargo vessels within the 1,000 to 10,000 DWT range built between 1985 and 2010. Roughly 1,800 of these were ice capable and registered either in Europe – European Union countries and other countries situated in Europe – or in a known flag of convenience country, such as Panama or Liberia. Even if a half of these are used in trade in North Europe, it is still a significant number of vessels which could be affected by emissions trading.

1.2 Previous studies of the subject

The global climate change discussion has been heating up in the last decade. The amount of studies on emissions and their impacts are far too numerous to account. The consensus at this point, I believe, is that global warming is a reality and something must be done to stop it. However, the debate on global warming and even the impacts of emissions on the environment are well beyond the scope of this study. This study concentrates especially on maritime industry and its' emissions.

As a research subject, emissions from shipping have been studied extensively by both independent research groups and research groups commissioned by, for example, IMO – *the 2000 IMO GHG Study* and *the Second IMO GHG Study 2009* are perfect examples of comprehensive shipping emissions studies. These two studies appear in many later studies as references. Quantifying shipping emissions seems to be a current subject of study and many of these studies are aimed at modeling and quantifying the emissions of the entire world's fleet.

For this research, the relevance of the previous studies can be divided into two different categories: the studies that concentrate on modeling and quantifying the shipping emission and the studies that evaluate the financial impacts of, for example, emissions trading. The relevant research for this study is introduced in greater detail in chapter 4.

A great portion of the theory chapters in this study are based on actual regulations and legislation, which leads to much of the reference material being directives and other official material provided by both the EU and the IMO.

1.3 The aim of this study and research problems

This study aims at quantifying the CO_2, SO_2 and NO_x emissions from ships and evaluating the financial impact of the above emissions for an individual ship owner.

Emissions' trading has been chosen as the main tool financial impact evaluation. This research aim can be formulated in to the following research questions:

Q1: How are the ship's emissions quantified mathematically?
Q2: What are the ship's annual emissions?
Q3: What are the possible financial impacts of the ship's annual emissions?

1.4 Limitations of this study

This study is aimed at quantifying ship emissions for individual companies based on their fleet characteristics. By no means is this study attempting to quantify the emissions of the world's entire fleet. The ships' size and the created ship emissions calculator – the *Marine Emissions Evaluator* – are best suited for a small dry bulk and general cargo ships. The trade area of the ship used in this study and emissions evaluated with the *Marine Emissions Evaluator* is North Europe due to its special restrictions on – for example – fuel sulphur content. Factors that present the limitations of this study are presented in Tables 1 and 2. Table 1 is ship related factors that either have an effect or do not have an effect. Table 2 presents some additional factors that are not presented in Table 1. Later chapters of this study will give detailed explanations on those factors that do affect the emissions in this study.

Table 1 Ship related factors that detail the limitations of this study

Factor	**Impact**	**How**
Size	Yes	Affects the size of the engine
Age	Yes	Affects the engine NO_x emissions limits
Nationality	No	Does not have an effect in this study
Engine type	Yes	Affects the engine NO_x emissions factors
Bunker type	Yes	Affects the CO_2 emissions and the SO_2 emissions
Cargo type	No	Different types of general and dry bulk cargo does not have effect
Fuel consumption	Yes	Evaluations are based on fuel consumption
Laden/Ballast	Yes	Affects the fuel consumption

Table 2 Other factors that detail the limitations of this study

Factor	**Impact**	**How**
Time frame	Yes	Affects the SO_2 and NO_x emission limits
Trade area	Yes	Affects the fuel sulphur limits
Ice conditions	No	Ice condition effects not taken into consideration directly

The Table 2 presents ice conditions as one of the limitations of this study. Ice conditions of course have an effect on emissions, but for scope of this study that detail is not taken into consideration directly. Indirectly ice conditions affect the fuel consumption, which in turn affects the emissions.

This study is not normative and it does not give an opinion whether maritime industry should or should not be included in the European Union Emissions Trading Scheme.

1.5 Structure of this study

This study will begin with a detailed introduction to emissions trading; theoretical background and a brief introduction to different emissions trading schemes around the world. After introducing different emissions trading schemes, the European Union Emissions Trading Scheme is reviewed extensively since the financial impacts are evaluated based on it.

After emissions trading chapter – which is more general in nature – the regulatory framework for emissions from international maritime industry is introduced. In this chapter, different engine types and the emissions from ships are covered.

Methodology and research design are talked about in chapter four of this study. After the methodology chapter the detailed mathematical modeling for emission quantification used in this study is presented. This chapter also includes two different ship emissions calculators that are presented in great detail.

The ship emissions calculator created for this study is utilized in chapter six to gain empirical data on emission quantities. These emissions are then evaluated based on their possible financial impact for the ship owner.

Lastly conclusions are drawn based on the findings of the study.

2 EMISSIONS TRADING

2.1 Theoretical background for emissions trading

2.1.1 *Historical development*

In the middle of 20th century in the United States the policy makers and the economists had very different and strong notions regarding the control of pollution. The economists believed in taxation of the pollutions per unit emitted, whereas the policy makers believed in setting legal regulations. The economists argued that the "command-and-control" systems – which the legal regulations were known as – were not cost-effective. The policy makers, however, argued that the amount of information needed to create a sufficient taxation system was too great. While the debate over merits of the different systems continued, the "command-and-control" legal regulations prevailed. (Tietenberg 2006, 2-3.)

The early idea on emissions trading was introduced in the 1960 by Ronald Coase (Tietenberg 2006, 3). His main idea was to think of pollution as property rights. Coase said (Tietenberg 2006, 3): "*If factors of production are thought of as rights, it becomes easier to understand that the right to do something which has a harmful effect (such as the creation of smoke, noise smell, etc.) is also a factor of production… The cost of exercising a right (of using a factor of production) is always the loss that is suffered elsewhere in consequence of the exercise of that right – the inability to cross land, to park a car, to build a house, to enjoy a view, to have peace and quiet or to breathe clean air.*" According to him, these property rights should be both transferable and explicit. Coase argued his opinion to both the economists and the policy makers with different points. To economists he said that the market would determine a true value for the rights and to the policy makers that the emission limits set by the regulation prevent the rights from going where they are the most effective. (Tietenberg 2006, 3.)

Dales and Crocker continued Coase's work independently, Dales applying the idea on water and Crocker on air. Dales also pointed out that the property rights suggested by Coase had already been created, except they lacked the important transferability. In the 1970s two different studies, first by Baumol and Oates and the second by Montgomery developed the idea even further. (Tietenberg 2006, 4-5.)

2.1.2 *Regulatory framework*

A comprehensive regulatory framework needs to be created for emissions trading systems. Tietenberg (2006, 25) concludes what he calls the Regulatory Dilemmas as: "*Two principal types of participants are crucial in the process of regulating the amount of pollution in the air. While the regulatory authority has the statutory responsibility for ensuring accepTable air quality, those managing the sources of the pollutant (such as industries, automobiles, power plants etc.) must ultimately take the action what will reduce pollution sufficiently to meet specified goals. The key to successful regulation is to design programs that harmonize the efforts of these two groups.*".

The regulators are in charge of creating a regulatory framework that works. This framework needs, for example, clear rules about allocation of allowances, either freely or by auction or by a combination of both. The regulatory framework cannot be so complex that enforcing it is impossible and participants cannot comply with the regulations. (Tietenberg 2006, 25.)

2.1.3 *A Cap-and-Trade system and emissions market*

Most of the emissions trading programs are cap-and-trade programs. The cap-and-trade system functions on basis of creating an insufficiency of the commodity, in this case an allowance to emit specified quantity of emissions. In order for the system to work the total amount of emission allowances, caps, needs to be lower than the total amount of emissions actually emitted. (MEMO/06/452 2006, 1.) This will create the desired environmental impact of the system, because the companies involved have fewer allowances than they actually need to emit and, therefore, investments in environmentally friendlier technology needs to be made. (Green Paper on greenhouse gas emissions trading within the European Union 2000, 8.)

Trading of the allowances between companies will create a market for the allowances and a price for carbon emissions. Companies that have more allowances than they require are allowed to sell them in the carbon market. Whereas, companies that are emitting more than their allowances give them right to, need to acquire more allowances or reduce their emissions. It all comes down to the price of the carbon allowances. If investments in emission reducing technologies are cheaper than the market price for allowances, the company will most likely invest in the technology. This creates incentives for companies that can reduce their emissions at the most affordable cost to do so first. Companies, to whom emission reduction technology is very expensive, may buy allowances from companies that can reduce their emissions in more cost-efffective way. This achieves the main goal of the system, overall reduction in emissions. (MEMO/06/452 2006, 1.)

In order for the cap-and-trade system to function as was meant, a working and cost-effective market for the emissions has to be created. The emission allowances have to be transferable by nature in order to allow the trading. The demand and supply of the emissions market determines the price for the allowance and, thus, helps companies' decision making: whether to invest in technology or purchase allowance. (Tietenberg 2006, 27.)

2.1.4 *Transaction costs, administrative costs and technical change*

There are numerous factors that affect the functioning of emissions trading systems and its' goals. Some of which are more important and fundamental than others. In this section three of these factors are presented. These are transaction costs, administrative costs and technical change.

The term transaction cost is the same as in any economics. Transaction costs are those that incur during trade for both buyers and sellers. These are example the cost of finding information, finding trade partner, negotiating with possible trade partners, preparing paperwork, issuing and receiving invoices etc. The list could be continued endlessly. However, in order for the system to function and be cost-effective, the transaction costs must be minimized. High transaction costs have a negative effect on trade. (Tietenberg 2006, 41.)

Whereas the transaction costs incur between the traders, the administrative costs are borne solely by the systems regulators. The more complex the system, the more likely it is that the administrative costs associated with it are, in correlation, very high. The administrative costs could be, for example, hiring staff to control compliance with regulations, keeping track of the permits and their trade, monitoring the emissions and so on. High administrative costs may even prevent the initiation of emissions trading in the first place. (Tietenberg 2006, 42.)

One of the fundamental aims of any emissions trading program is to provide incentives for technological innovations that reduce emissions. The way in which the emissions trading program is set up and its' regulations have a remarkable impact on the technological innovativeness of the companies. Simply put: the auctioning of emissions allowances instead of free allocations gives more incentives for companies to reduce their emissions. (Tietenberg 2006, 43.)

2.1.5 *Examples of emissions trading programs outside the European Union*

2.1.5.1 *Kyoto Protocol*

The Kyoto Protocol refers to the legally binding emission reduction targets for carbon dioxide, methane, nitrous oxide, HFCs, PFCs and sulphur hexafluoride. These targets are for the industrial economies and the economies in transition, and where set at the Kyoto Conference in 1997 under the UNFCCC. Kyoto Protocol is the first truly international emissions trading system. However, the Kyoto Protocol did not enter into force until Russia ratified the agreement in 2005. (Tietenberg 2006, 15.) This was due to the way in which the Protocol was formulated. In order for it to become effective part of international law, 55 of the more developed countries accounting for 55 % of the total greenhouse gas emissions had to have ratified the treaty. With Russia ratifying the agreement, the total emission percentage was brought to 61 %. (Giddens 2009, 187.)

The baseline year to which emissions would be compared to, was agreed to be 1990. On average the developed nations would have to decrease their emissions by 5.2 % compared to the baseline year. The period during which these emission reductions are meant to take place is from 2008 to 2012. (Giddens 2009, 187.) This period is also known as the Kyoto Commitment period.

The Kyoto Protocol introduces three mechanisms for reaching these targets. These are Emissions Trading, Joint Implementation and the Clean Development Mechanism (Tietenberg 2006, 15).

Emissions trading created a new commodity for trade. As a reduction mechanism, the emissions' trading allows countries to trade emission units with one another. The countries' – that have agreed to the emission targets for 2008-2012 – emissions targets are "*expressed as levels of allowed emissions, or "assigned amounts""* The name for these units is Assigned Amount Units (AAUs). (Kyoto Protocol, Emissions trading.)

The second tool under Kyoto Protocol is the Clean Development Mechanism (hereafter referred to as CDM). The countries which have emission target commitments under Kyoto Protocol can utilize the CDM projects in countries that are not under Kyoto Protocol. The allowance units gained from CDM projects are called Certified Emission Reduction (CER) credits and they can be used just like the AAUs to help meet the emission reductions targets set in the Kyoto Protocol. (Kyoto Protocol, Clean Development Mechanism.)

The third mechanism in Kyoto Protocol is the Joint Implementation (hereafter referred to as JI). Whereas, CDM projects were between Kyoto committed countries and other countries, the JI projects are between two Kyoto committed countries. The name of the allowance units gained from JI projects are Emission Reduction Units (ERUs).

They can be used just like the CER credits could be used. (Kyoto Protocol, Joint Implementation.) Both CERs and ERUs are equal to one tonne of CO_2 emissions.

One of the problems with the Kyoto Protocol is that it is not applicable to two major industries: aviation industry and maritime industry (Second IMO GHG Study 2009, 34). The emissions reductions responsibilities from these industries have been assigned to their respective international organizations.

2.1.5.2 *Emissions Trading in the United States*

During the last decades the United States has had different emissions trading schemes battling different pollutants. Some of these have functioned on national level with federal regulation and other on state level with state regulation. One of the most successful emissions trading systems in the US has been fighting sulphur dioxide emissions, and therefore, acid rain. The program was called *The Sulfur Allowance Program*. The Environmental Protection Agency (EPA) created a market for sulphur emission allowances that were sold at The Chicago Board of Trade. This solved one of the problems the earlier emissions trading systems had: the price of the emissions allowance was no longer confidential between buyer and seller but public knowledge, creating needed transparency to the system. The other major difference this program had compared to others was that it allowed anyone to purchase the allowances. This means that even an environmental group could buy and "retire" the allowances. This leads to a situation where the over-all allowance quantity would be lowered and so would the total emissions. (Tietenberg 2006, 11-12.)

The change from Bush Administration to Obama Administration has led the United States of America on the road to more climate controlled future. The current emissions trading situation in the US is that, in June 2009 the House of Representatives passed a bill called the *American Clean Energy and Security Act of 2009 (ACES)* with 219 votes in favour and 212 against. The bill is currently under consideration at the US Senate. The bill would create a cap-and-trade system for "*heat-trapping*" gases, which are those that remain in the earth's atmosphere and cause the greenhouse effect. The emitters would initially receive allowances, but eventually they would have to buy their allowances at an auction. The gap would be tightened each year in order to get the desired emission reduction results. The commencement for the program has been planned for 2012. (Broder 2009.)

Many amendments had to be made into the bill before it passed. This has lead to dissatisfaction, especially among the environmental groups. The bill also fails to meet the hopes the European Union had for it. Parties in favor of the bill in the beginning have also expressed their dissatisfaction in the bill because all the amendments that were made rendered the bill less effective. (Broder 2009.)

2.2 The European Union Emissions Trading Scheme

2.2.1 ***Regulatory framework of the European Union Emissions Trading Scheme***

The most comprehensive emissions trading system in the world is the European Union Emissions Trading Scheme (hereafter referred to as EU ETS). The EU ETS was largely formed to be a solution for reaching the Kyoto Protocol emission reductions. *The Green Paper on greenhouse gas emissions trading within the European Union* was published on March 8th 2000 and its' aim was to start discussion and debate on the subject of emissions trading within the EU. Both governmental and non-governmental stakeholders were free to express their opinion on the subject. The Commission believed that: "*A coherent and co-ordinated framework for implementing emissions trading covering all Member States would provide the best guarantee for a smooth functioning internal emissions market compared to a set of unco-ordinated national emissions trading schemes.".* As the Kyoto Protocol emissions trading system was commencing in 2008, there was a wide-held believe that commencement of EU ETS in 2005 would give enough time for a learning phase before the commencement of Kyoto system. In accordance with the already existing emission control tools, such as taxes, regulations and technical standards, the emissions trading scheme was believed to enhance the positive effects on the environmental preservation. (The Green Paper on greenhouse gas emissions trading within the European Union 2000, 1-7.)

The responses to the Green Paper were numerous and most of them were in favour of emissions trading in Europe. Comprehensive discussions and further analysis within the European Climate Change Programme on emissions trading has been held, which increased the understanding of emissions trading as a system. Stakeholders, such as member states, were consulted on the subject and the clear support for emissions trading led to creation of proposal for a Directive. (Proposal for a Directive of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, 2001, 2.)

The proposal for a directive eventually led to *Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.* This Directive has since then been amended several times, such as when the aviation industry was included into the EU ETS. This Directive will without a doubt be amended again in the future as changes are made in preparation for the third trading period and inclusions of additional industries under the EU ETS.

2.2.2 *Linking Kyoto Protocol and European Union Emissions Trading Scheme*

As mentioned above, the EU ETS was in many ways created to be an answer to meeting the Kyoto Protocol targets. The European Union countries that participate in CDM or JI projects can obtain additional emissions allowances that they can then sell off to companies under the EU ETS (EU action against climate change 2009a, 23). This provides an additional tool for cost-effective decreasing of the over-all emissions. Giddens (2009, 199) states that the EU ETS is the reason that the CDM system is currently in operation.

2.2.3 *The commencement and the aims of European Union Emissions Trading Scheme*

The European wide emissions trading scheme for carbon dioxide (CO_2) emissions was launched in 2005. The European Union was not the first to set up an emissions trading scheme, however, it is the largest program consisting of different nations as well as various industries (EU action against climate change, 2009, 5). In the first phase of EU ETS the program included over 11,500 energy-intensive installation around Europe. These installations, which were in the fields of combustion plants, oil refineries, coke ovens, iron and steel plants etc, accumulated to almost half of all CO_2 emissions in Europe. (MEMO/05/84, 2005.)

Participation in the EU ETS is mandatory for all of the 27 EU member states. Addition to this, Norway, Liechtenstein and Iceland participate in the EU ETS from 2008 onwards. (EU action against climate change 2009a, 5-6.)

The EU ETS was introduced in order to limit and reduce anthropogenic – meaning the emissions caused by human actions – greenhouse gas emissions in a cost-effective way. The European Commission has stated that the developed countries should reduce their greenhouse gas emissions by 30 % from 1990 levels by 2020. The EU has stated that it will reduce its emissions by 20 % and when the rest of the developed countries reduce their greenhouse gas emissions the combined emissions reduction should reach the desired 30 % below the 1990 level. (Giddens 2009, 193.)

Kyoto protocol plays an important role in the EU ETS system as its targets are the basis of EU emission reduction targets. In order to create worldwide emissions trading market the EU ETS has formed agreements with similar cap-and-trade systems around the world. (EU action against climate change 2009a, 5-6.)

2.2.4 *First, second and third phase of the European Union Emissions Trading Scheme*

As the EU ETS was first of its kind, – a truly multinational emissions trading scheme – an emissions market of the same magnitude did not exist, based on which the EU ETS could be modeled from. The first phase, from initiation in 2005 to 2007, is therefore, considered to be a trial phase for the EU ETS (Tietenberg 2006, 16). The EU calls this stage the "learning by doing" stage. The aim of the first phase was to create a working carbon market in which emissions allowances could be traded and establish a price for the emission allowances. (EU action against climate change 2009a, 8.) One emission allowance equals a right to emit one tonne of CO_2 emissions (MEMO/06/452 2006, 1). Because the whole system was new, the entire infrastructure it needed such as the systems for monitoring, reporting and verifying of the emissions, had to be created. Another crucial part of the first phase was the collection of specified statistical data on actually emitted emission, in order to determine a more realistic allowance caps for the important second phase of the EU ETS. (EU action against climate change 2009a, 8.)

Second phase of EU ETS commenced on January 1st 2008 and will continue until the end of 2012. The first phase of the EU ETS gathered specified data on the actual emission amounts; and they were taken into account when National Allocation Plans (hereafter referred to as NAPs) were formulated for the second phase of the EU ETS. Second phase of the EU ETS is crucial, as it is what is called 'first commitment period' of Kyoto Protocol targets. It means that the member states must meet their emissions targets set in the Kyoto Protocol. (EU action against climate change 2009a, 8.)

Third phase of EU ETS will being January 1st 2013 and continue until end of 2020. The third phase of EU ETS is designed to be the longest continuous run of the EU ETS so far. The 8 year period was agreed upon in order to create more predictability for the system. This is will encourage long term investments in emission reduction technology. (EU action against climate change 2009a, 8.) The third phase of the EU ETS will be revised and rules harmonized in other ways as well. Among the major changes is the inclusion of, at least, the aviation industry, into the EU ETS. National allocation plans will be replaced by a common Europe-wide cap on allowances. The European Commission has already published its' plan to cut the cap on allowances linearly by 1.74 % each year until 2020 and even further. This will ensure the emissions reduction targets formulated in the Kyoto Protocol are met. The announcement of the linear reductions of allowance caps will bring much needed predictability to the system, which will in turn assists the investment decisions on emission reducing technology. The change that will affect all of the companies' most, in the EU ETS, is the removal of free emission allowances which are to be replaced by auctioned allowances. The goal is that from 2013 onwards, at least 50 % of all allowances will be auctioned off. Full auctioning of allowances should be reached by 2027 with few exceptions. (EU action against climate change 2009a, 11-12.)

2.2.5 *National Allocation Plans and allowance auctioning*

2.2.5.1 *What is a National Allocation Plan*

National allocation Plans (NAPs) are a central part of the EU ETS system. Member states are required to draw up an allocation plan for each trading period, first trading period being from 2005 to 2007, second 2008-2013 and third 2013-2020. The NAP must contain exact allowance quantities member states plans on giving to every single installation under the EU ETS system and the combined amount of emission allowances for that country. Each member state prepares its' own NAP. After the member states have prepared the NAPs, they are sent to the European Commission for inspection and approval. (EU action against climate change 2009a, 9, 15-16.) The European Commission can approve the plan fully, conditionally or refuse to accept it completely. No changes can be made to fully approved NAPs and the member state can move on to applying the NAP in practice. If the NAP is only partly approved, it needs to be altered in the aspects the European Commission requires before it can be implemented. (MEMO/06/452 2006, 2-3.)

Article 9 of the Directive 2003/87/EC (2003) states that the NAPs "*shall be based on objective and transparent criteria, including those listed in Annex III*". The NAP criteria in Annex III include provisions about number of things. Such as, a complete list of companies covered in the EU ETS system and number of emissions allowances allocated to them. NAPs cannot favor companies or industry at the expense of others. The criteria also state that the NAPs must prepare for comments from the public and plan how these comments will be taken into account before final decisions are made about the allocations. Attention must be paid to competition within the EU ETS system and outside it and competitiveness of the companies should be taken into consideration. (Directive 2003/87/ EC 2003, 5, 12.)

One of the main drivers according to which the allocations are distributed is the Kyoto Protocol targets (Giddens 2009, 198-199). The Kyoto Protocol must be taken into account when member states are formulating their NAPs, because EU ETS aims at reduction of overall emissions and meeting the national emission reduction targets set by the Kyoto Protocol. Limiting emissions allowances in sectors under EU ETS system leads to emissions being reduced in sectors where it is most cost-effective, instead of other sectors of the economy in which the reductions might not be made as effectively. (EU action against climate change 2007, 13.) Meeting the Kyoto Protocol requires reductions, not only in industries under EU ETS, but other sectors of industry as well. However, reduction can be made more effectively in industries under the EU ETS due to its' emission market component.

Member states in the EU ETS system can use the Kyoto instruments CDM and JI in their NAPs. The CDM and JI projects can be used in order for the member states to achieve their emissions targets. A member state participating in CDM and JI projects can provide its' companies more emissions allowances and, therefore, they can emit more. The CDM and JI projects have to be validated, for example through budgetary provisions, before they can be accounted for. (EU action against climate change 2007, 11.)

2.2.5.2 *The first allocation and the verified emissions for 2005-2007*

The European Commission recommended auctioning off the emission allowances starting from first phase of the EU ETS, but this was met with strong opposition from industry lobbyists. A compromise was reached between the European Commission and the member states. The member states were given the right to allocate their allowances according to their own judgment. (Giddens 2009, 198.) Member states could not, however, distribute as many allowances as they wanted, because national allowance cap was predetermined by the European Commission. (Tietenberg 2006, 16.) The European Commission approved the National Allocation Plans (NAPs) once they were completed (EU action against climate change 2009a, 16). Most of the NAPs for the first trading period were accepted fully or conditionally during 2004, but 4 of the NAPs were accepted only after the first trading period had begun in 2005 (MEMO/05/84 2005). As stated above, one of the main goals of the first phase of EU ETS was to create statistical data on actual emissions. Due to this, some of the initial allowances were allocated without adequate information concerning the actual emissions. The allowance allocations in the first phase were generally too abundant, since member states were trying to get as many allowances as possible (Giddens 2009, 199).

According to the European Energy Agency publications "Application of the Emissions Trading Directive by EU Member States" (2009, 14-16) the allocations by the member states were very inconsistent. Table 3 lists the verified emissions for the first phase of the EU ETS and the average allocations of that period. Only a few member states had higher actual verified emissions than allowances to cover them. Whereas, in 14 member states, the verified emissions were more than 10 % lower than allocated allowances at least in one year of the three year trading period. (Application of the Emissions Trading Directive by EU Member States 2009, 14-16.) The total Europe-wide verified emissions for each year of the first trading period were lower than the combined emission allowance quantity for that year.

Bulgaria, Romania and Malta are excluded from the data for different reasons. (IP/08/787 2008.)

Table 3 Verified carbon dioxide emissions for 2005-2007 (modified from IP/08/787 2008)

Country	Verified CO_2 emissions in millions of tonnes per year			Annual average allocation in 2005-2007 in millions of tonnes per year
	2005	2006	2007	
Austria	33.37	32.38	31.75	32.90
Belgium	55.36	54.78	52.80	62.11
Cyprus	5.08	5.26	5.40	5.70
Czech Republic	82.45	83.62	87.83	97.27
Germany	474.99	478.01	487.00	498.39
Denmark	26.48	34.20	29.41	33.50
Estonia	12.62	12.11	15.33	18.95
Spain	183.63	179.71	186.50	178.84
Finland	33.10	44.62	42.54	45.50
France	131.26	126.98	126.63	154.91
Greece	71.27	69.97	72.72	74.40
Hungary	26.16	25.85	26.84	31.66
Ireland	22.44	21.71	21.25	22.32
Italy	225.99	227.44	226.37	223.07
Lithuania	6.60	6.52	6.00	12.27
Luxemburg	2.60	2.71	2.57	3.36
Latvia	2.85	2.94	2.85	4.56
Netherlands	80.35	76.70	79.87	88.94
Poland	203.15	209.62	209.60	237.84
Portugal	36.43	33.08	31.18	38.16
Sweden	19.38	19.88	15.35	23.21
Slovenia	8.72	8.84	9.05	8.74
Slovakia	25.23	25.54	24.52	30.49
United Kingdom	242.51	251.16	256.58	224.83
Total	**2,012.04**	**2,033.64**	**2,049.93**	**2,151.93**

2.2.5.3 *The Second Allocation*

The second emission allocations were made especially firm in order for the member states to be able to meet their Kyoto Protocol targets. This goal was aided by the fact that verified emissions for 2005 had been published. This collection of data was the first of such magnitude. This data allowed the European Commission to make cuts from the actual emission quantities. The amount of emission allowances were reduced from 2005 levels by 6.5 % by the European Commission for the second phase of EU ETS. By doing this the European Commission aims to ensure that actual reductions are being made in emissions emitted and Kyoto targets are met. (EU action against climate change 2009a, 16.)

The second trading period is the 'first commitment period' of the Kyoto Protocol, which means that during this time the member states are trying to lower their emissions below the emissions levels of a pre-set base year. This base year is in most cases 1990. The EU-15 countries are trying to lower their combined emissions by 8 per cent. Varying targets have been set for the countries, which are binding for them. The countries that joined the EU during 2004 to 2007 have their own binding Kyoto Protocol targets which they are trying to meet. (EU action against climate change 2009a, 14.)

From Table 4 we can observe the Kyoto target that the member states are trying to meet, this is calculated in relation to the base year. The Table 4 also shows us the allowances for periods 2005-2007 and 2008-2012 and each member state's percentage share of the total EU ETS allowances. The total amount of emissions allowances for the period 2008-2012 is indeed smaller than the amount for 2005-2007.

Table 4 The European Union Emissions Trading Scheme allowances per member state for 2005-2012 (EU action against climate change 2009a, 14)

COUNTRY****	Kyoto target (% change against base year)	2005-2007		2008-2012	
		Allocated CO_2 allowances (million tonnes per year)	Share in ETS	Allocated CO_2 allowances (million tonnes per year)	Share in ETS
Austria	-13.0 %*	33.0	1.4 %	32.3	1.5 %
Belgium	-7.5 %*	62.1	2.7 %	58.0	2.8 %
Bulgaria	-8.0 %	42.3**	1.8 %	42.3***	2.0 %
Cyprus	-	5.7	0.2 %	5.2	0.3 %
Czech Republic	-8.0 %	97.6	4.2 %	86.7	4.2 %
Denmark	21.0 %*	33.5	1.4 %	24.5	1.2 %
Estonia	-8.0 %	19.0	0.8 %	11.8	0.6 %
Finland	0.0 %*	45.5	2.0 %	37.6	1.8 %
France	0.0 %*	156.5	6.8 %	132.0	6.3 %
Germany	-21.0 %*	499.0	21.7 %	451.5	21.6 %
Greece	+25.0 %*	74.4	3.2 %	68.3	3.3 %
Hungary	-6.0 %	31.3	1.4 %	19.5	0.9 %
Ireland	+13.0 %*	22.3	1.0 %	22.3	1.1 %
Italy	-6.5 %*	223.1	9.7 %	201.6	9.7 %
Latvia	-8.0 %	4.6	0.2 %	3.4	0.2 %
Lithuania	-8.0 %	12.3	0.5 %	8.6	0.4 %
Luxembourg	-28.0 %*	3.4	0.1 %	2.5	0.1 %
Malta	-	2.9	0.1 %	2.1	0.1 %
Netherlands	-6.0 %*	95.3	4.1 %	86.3	4.1 %
Poland	-6.0 %	239.1	10.4 %	205.7	9.9 %
Portugal	+27.0 %*	38.9	1.7 %	34.8	1.7 %
Romania	-8.0 %	74.8**	3.2 %	73.2	3.5 %
Slovakia	-8.0 %	30.5	1.3 %	32.5	1.6 %
Slovenia	-8.0 %	8.8	0.4 %	8.3	0.4 %
Spain	+15.0 %*	174.4	7.6 %	152.2	7.3 %
Sweden	+4.0 %*	22.9	1.0 %	22.4	1.1 %
UK	-12.0 %*	245.3	10.7 %	245.6	11.8 %
Liechtenstein	-8.0 %			0.2	0.0 %
Norway	1.0 %			15.0	0.7 %
Total		**2,298.5**	**100.0 %**	**2,086.5**	**100.0 %**

* Under the Kyoto Protocol, the EU-15 (the group of 15 countries that were EU Member States before 2004) are committed to reducing their collective greenhouse gas emissions to 8 % below levels in a chosen base year (1990 in most cases) during 2008–12. This collective target has been translated into differentiated national targets, marked by (*), through a legally binding agreement (Council Decision 2002/358/EC of 25 April 2002). The 12 Member States that joined the EU in 2004 and 2007 have their own binding national targets under the Kyoto Protocol with the exception of Cyprus and Malta, which have no targets.

** Only for 2007

*** Provisional

**** Iceland is part of the EU ETS but at present none of its installations participate.

2.2.5.4 *The third allocation and auctioning*

The system of distributing emissions allowances changes significantly for the trading period 2013 to 2020. At this point the NAPs are replaced by a European-wide cap on emission allowances. The aim of the change is to make sure that emission reduction targets for 2020 are met. This change will also unify the process of emissions allowance allocating. (EU action against climate change 2009a, 17.)

As stated earlier in chapter 2.2.4 the plan is to cut the emission allowances linearly by 1.74 % each year until 2020 and beyond. This reduction in cap will commence at the mid-point of the 2008 to 2012 period. This will lead to emissions in 2020 being 21 % lower than the verified emissions of 2005, which means that the emission targets set for year 2020 are achieved. (EU action against climate change 2009a, 17.)

The other significant change to the system from the earlier periods is the auctioning of emission allowances. Whereas before, the member states have been able to allocate the emission allowances to the companies in their countries for free, now the auctioning of the allowances will commence. The auctioning of the allowances will stimulate the companies to invest in emission reducing technology well in advance. (EU action against climate change 2009a, 17.)

The auctioning of allowance will progress in steps, but the power generation sector is treated differently from other sectors. The auctioning in other sectors will begin in 2013 with 20 % of the emission allowance being auctioned. By 2020 70 % of all the emission allowances should be auctioned with full auctioning reached by 2027. Some exceptions may be made for some energy-intensive industries if their competitiveness is in jeopardy. For the power generating sector, the principle is that they purchase 100 % of their emissions allowance starting from 2013. However, there are rules under which the governments may grant 70 % of the emission allowances to the companies in power generation sector in 2013. The amount will decrease every year reaching zero by 2020. It is estimated that because of the weight of the power generating sector, 50 % of the emission allowances will be auctioned in 2013. (EU action against climate change 2009a, 17-18.)

In practice the auctioning will be done by governments according to the rules set by the European Commission. The rules will be presented by June 30th 2010 and their aim is to ensure that the auctioning is open, transparent and non-discriminative. It is estimated that by 2020 the governments could gain a combined sum of 30-50 billion per annum from the auctioning. However, agreement has been made that at least 50 % of this should be used to fight climate change both in Europe and other parts of the world as well. (EU action against climate change 2009a, 18.)

2.2.6 *Electronic transaction registries*

To keep track of all the allowances in circulation an electronic registry system was created. This system operates on two levels – national and Europe-wide – and it is kept separate from the trading system of emission allowances. The national registries keep track of allowances issued to companies in their home state and the national register registers changes in ownership that are result of emissions trade. (MEMO/06/452 2006, 9.)

The allowances are only kept in electronic form in these registries and no paper versions of them exist. Banking system may be compared to the electronic registry system, because its function is to keep track of the allowances, but not look into trades that result in change of ownership of the allowances. The European-wide level of the registry system reviews each transaction for problems and none of the transactions are completed before the inspection. The registry system is also combaTable with international registries that are used for Kyoto Protocol. (EU action against climate change 2007, 13-14.)

2.2.7 *Market and the commodities of the European Union Emissions Trading Scheme*

One of the main factors in making the EU ETS function, and some other emissions trading systems as well, is that, just like any other free market, the price of the commodity is determined by demand and supply of said commodity. The EU does not get involved in the price development of the allowances. If there are problems the common competition laws protects the system. (MEMO/06/452 2006, 1.)

The EU does not control where the trading in EU ETS allowances takes place. Trading may take place directly between the EU ETS involved companies, via brokers, banks or other institutions. (MEMO/06/452 2006, 9.) There are several market places for trading emissions allowances. The leading market in Europe is the European Climate Exchange (hereafter referred to as ECX). Trading at the ECX is done in European Union Allowances (hereafter referred to as EUA) and in Certified Emission Reductions (hereafter referred to as CERs). These commodities can be traded on futures and spot basis. The ECX belongs to group of companies called Climate Exchange Plc. Other company that also belongs to the group is, for example, Chicago Climate Exchange. (European Climate Exchange 2009.)

The main EU ETS commodity is the EUA. EUA credits relate to the emissions allowances discussed earlier in this chapter. They are the allowances that companies receive from the government under the NAPs. EUAs are the most basic of the EU ETS commodities.

The other commodities that are traded in the EU ETS system are CERs and Emission Reduction Units (hereafter referred to as ERUs). CERs and ERUs are linked to the Kyoto Protocol programs CDM and JI. The credits companies may receive from CDM projects are CERs and credits from JI projects are ERUs. (EU action against climate change 2009a, 23.)

The EU ETS leads the way in international cooperation in emission credits. One of the other emission credits – CERs or ERUs – are considered equal to EUAs, so that 1 EUA = 1 CER = 1 ERU. These credits can be traded equally to EUAs. (EU action against climate change 2009a, 23.)

2.2.8 *Price development of European Union Allowances*

Giddens (2009, 199) argues that the EU ETS has not performed efficiently in the task it was set up to perform. In the beginning of carbon trading, the price of emission allowance reached 31 Euros per tonne, but it would subsequently fall to practically zero. This was due to the generous initial allocations among the member states.

The price decline to zero can also be observed from Figure 1. The price for the first phase allowances is green and red for the second phase allowances in the Figure 1. The price for the first phase EUAs began a steady decline in the summer of 2006. Single, biggest drop came after the verified emissions data for the first trading year, 2005, was published and the over generous allocations became apparent. This fact was corroborated at the latest when the verified emissions for the second year of trading, 2006, were published in the spring of 2007. Because of the apparent over allocations the EUAs had completely lost their value by the last trading year of the first phase.

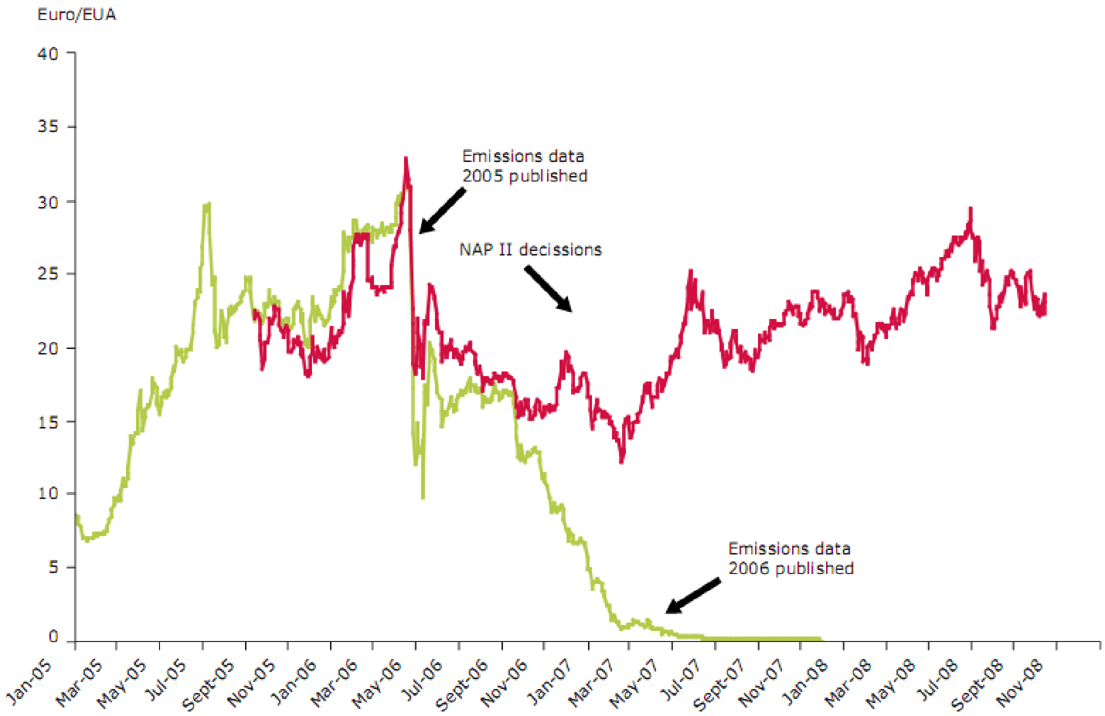

Figure 1 European Union Emissions Trading Scheme over-the-counter European Union Allowance closing prices 2005–2008 (Application of the Emissions Trading Directive by EU Member States 2009, 16)

Trading for the second phase of the EU ETS was well on the way during the first phase. The price was very volatile before the publication of final NAPs for the second phase in the summer of 2007. The price increased after the publication of NAPs for the second trading phase. The publication of the NAPs for the second phase informed traders of the more strict caps set for phase two by the European commission. By the end of 2008 EUA prices were over 20 € per EUA.

In February of 2009 EUA prices were below 10 € per EUA, which was the record low for the second phase EUAs. The economic crisis has also had an effect on the EUA prices. The decline in production due to recession will lead to smaller emission amounts, which results in companies having unneeded emission allowances that they are trying to sell, bringing the price further down. (Carbonpositive 2009.) The sale of the excess allowances has worked as an extra source of liquidity for the companies dealing with declines in production. Impact of the recession can be felt strongly, for example, in steel and cement industry, which are considered to be big polluters in normal situations. The economic recession has, therefore, brought on unplanned side effects to the emission trading. (Reuters 2009.)

The Copenhagen Climate Summit and the weak result of the summit had the EUA prices going down. After the Summit the EUA prices reached the lowest point in the last quarter of 2009 (Vertis Finance 2009). From Figure 2 it is clear that the EUA prices started falling during the Summit and reached the lowest point right after the Summit concluded around 20th of December 2009. The EUA prices fell over 2 EUR per EUA within 2 weeks.

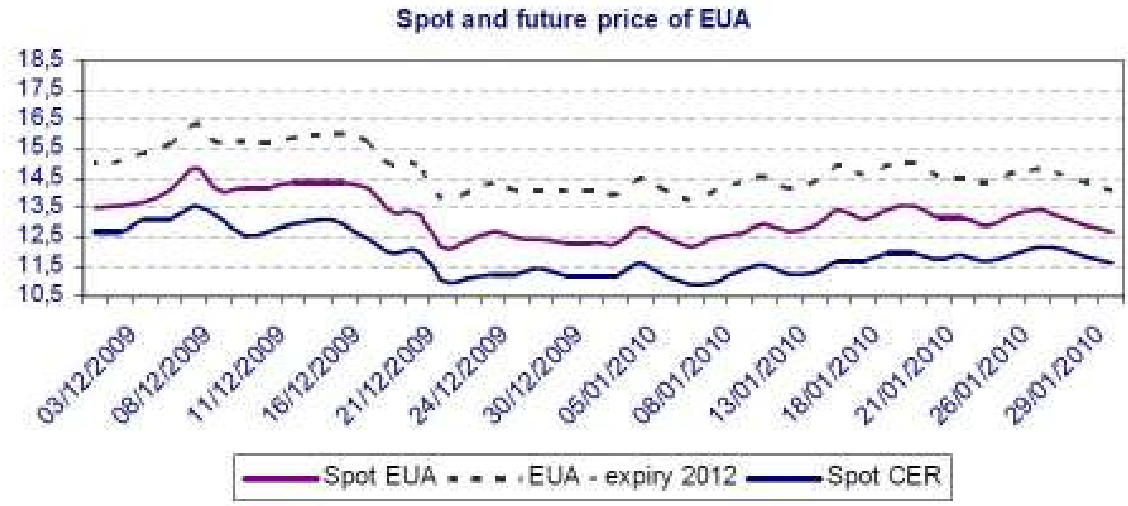

Figure 2 European Union Allowance and Certified Emission Reductions prices in December 2009 – January 2010 (Vertis Finance - Carbon Newsletter January 2010)

The prices of EUAs remained at a lower level in January 2010 than they were before the Copenhagen Summit. Not even the unusually cold winter had a significant effect on the EUA prices or the fact that there is doubt about the commitment of the European Union to the set CO_2 emission reductions. (Vertis Finance 2010.) The EU maintained its promise to reduce CO_2 emissions by 20 %, whereas, some member countries would have wanted to commit to a higher, 30 % reductions.

There is an expected surplus of emission allowances for the trading period 2008-2012 despite all the efforts of the EU. The actual surplus is expected to reach over 160 million allowances. Vertis Finance (2010) states that *"The political insecurities, the negative sentiments and the weak carbon fundamentals reduce the probability of any significant price increase in the short run."*

2.2.9 *Inclusion of aviation industry into the European Union Emissions Trading Scheme*

With the growth of the aviation industry, the negative environmental impacts of it are increasing. From 1990 to 2006 the total emissions in the European Union fell by 3 %, during which time the emissions from aviation industry increased by 100 %. The technical improvements and better operational efficiency have not been able to off-set the increasing emissions from aviation. With the continuing growth of the aviation industry, the emission amounts are expected to grow furthermore. (Aviation and Climate Change, 2010.) Directive 2008/101/EC (2008, (11)) states: "*If the climate change impact of the aviation sector continues to grow at the current rate, it would significantly undermine reductions made by other sectors to combat climate change.*"

The inclusion of aviation industry into the EU ETS has been without a doubt very controversial subject. The European Union hoped that the International Civil Aviation Organization (hereafter referred to as ICAO) would be able to come up with a solution to the problem by 2002. However, no such agreement was reached within the ICAO in the time agreed upon in the EU and the EU decided to include aviation to its' EU ETS program. The ICAO even stated in 2004 that: *"…an aviation-specific emissions trading system based on new legal instrument under ICAO auspices seemed sufficiently unattractive that it should not then be pursued further."* (Directive 2008/101/EC, (9),(10).) The International Air Transport Association (hereafter referred to as IATA) was also opposed to the EU ETS decision even though in general they are not opposed to emissions trading for aviation industry. The IATA Director General and CEO Giovanni Bisignani said of the decision: "*Crisis is not the time for rubber stamps. But that is exactly what the Council of Justice and Home Affairs Ministers used today – without a word of debate – to seal into law the EUR 3.5 billion cost of bringing airlines into the European ETS. It's Brussels acting in a bubble – even in the middle of a global economic crisis.". (IATA Press Release 24.10.2008.)*

Directive 2003/87/EC establishes the emissions trading scheme in Europe and Directive 2008/101/EC amends this Directive to include the aviation industry to the EU ETS. The first period – when aviation operators must have emission allowances to cover their emissions – is from January 1st to December 31st 2012. Article 3c (1) of Directive 2008/101/EC states that the aviation industry will be allocated allowances that are equal to 97 % of the historical emissions quantities. These historical emissions were decided upon during 2009 (Directive 2008/101/EC, Article 3c (4)). In the first period – 2012 – 15 % of the emission allowances will be auctioned. Starting from 2013 15 % will also be auctioned, however, this figure may be increased in the review of the Directive (Directive 2008/101/EC, Article 3d (1-2).

In order for the system to be fair, all flights arriving at or departing from airports within the Community are included into the EU ETS no matter the nationality of the aviation operator (Directive 2008/101/EC (16)).

The aviation industry is very different from currently participating companies in the EU ETS. All the previous installations participating in EU ETS are stationary, whereas, aviation is mobile. Determining the administrative member state for an aviation company is a bit different than to the stationary installations. In practice, each aviation operator will be designated to an administrative member state with which they will deal with when it comes to verifying emissions and receiving free allowances. The designation of an administrative member state to an aviation operator will be done according to the rules set in the Article 18a of the Directive 2003/87/Ec.

The European Union has created an example emission monitoring plan, which can be found at their website. This emission monitoring plan is a comprehensive plan to assess the emissions created by aircraft operations. The plan contains different calculation parameters and emission factors for the user to choose from. (Monitoring, reporting and verification of aviation 2010.) However, the verification of the emissions must be done before they are accepted.

Review based on experience of the functioning of the EU ETS in relation to aviation industry shall be done no later than December 1st 2014 by the Commission. During the review attention will especially be paid to, for example, the performance of the emission market in relation to aviation, environmental viability of the program, the impact on the aviation sector etc. (Article 30 (4a-d) of Directive 2003/87/EC.)

2.2.10 *Maritime industry and the European Union Emissions Trading Scheme*

Maritime industry and emissions trading is a very complex issue. Currently international maritime industry is not under any emissions trading schemes, but that may change in the near future. The International Maritime Organization (hereafter referred to as IMO) has been working for years to come up with solutions in order to control the maritime emission. One of the possibilities is market-based instrument, emissions trading. However, the progress IMO has made in this is next to nothing.

Due to IMO's lack of progress in the matter, the European Union has agreed that it will add maritime industry under the EU ETS. The deadline the EU has set for IMO to come up with a solution is the end of 2011. If by then, there is no progress made, the EU will add maritime industry under the emissions trading scheme. And considering that IMO's progress so far has been a decision to discuss the matter further, the probability of IMO coming up with a solution is small. If maritime industry is indeed added to the EU ETS the commencement is likely to be in 2013, at the start of the third trading period. (ENDS Report 414, July 2009.)

The emissions amounts from ships continue to grow in the future as the volume of international trade grows, which is why it is important that solutions to these emission problems are found. Forecasts for growth of shipping emissions for 2050 are predicted to be somewhere around 150 % to 250 % compared to emissions in 2007 (Second IMO GHG study 2009, 9).

Right now it is impossible to say what will happen in relation to maritime emissions and EU ETS. However, it is likely that maritime industry will be added to the EU ETS system just like aviation industry was. Predicting the ways and rules of linking maritime industry to the EU ETS is just as hard. One might assume that some indication may be gained by studying the aviation industry inclusion to the EU ETS, but it has to be remembered that these two industries are very different even though both are part of the transportation industry.

2.2.11 *Criticism for the European Union Emissions Trading Scheme*

Concerns have been voiced about the impacts of the EU ETS on the competitiveness of the companies functioning in Europe. These concerns are expressed especially by the industry representatives who fear that the rules set by the EU will result in companies moving to areas where environmental regulations are not so strict. This is possible since the EU is ahead of the rest of the world in battling climate change. The soundness of these concerns has been admitted by the Commission President José Manuel Barroso. (Giddens 2009, 195.)

Carbon markets have grown tremendously in the last five years. The World Bank has estimated the combined value of all the carbon markets around the world, the biggest of which is the EU ETS market, in 2007 was $ 64 billion. However, the intent of EU ETS was not to create another market of change, but actual reductions in emissions. The emission exchange markets goal is mainly to function as a tool in order to achieve the end result, lower emissions. Currently there are large quantities of money involved in the market, but it is very hard to evaluate the actual impact the market has on lowering the emissions. (Giddens 2009, 200.)

One argument against the EU ETS is the emission caps that it has set for the coming years until 2020. The emission allowances were made in when the economy was strong and growing. The current economic crisis has indicated that the set emission caps may be too lenient for the future. If there are excess allowances on the market, the EUA prices will decline and the incentive for the companies to invest in environmentally friendlier technology may cease to exist. (Reuters 2009.)

2.3 Voluntary emissions trading

Some of the emissions trading systems in the United States have focused on different pollutants. However, the emissions trading currently applicable in the EU ETS is only for carbon dioxide, CO_2, emissions, which leaves major pollutants, such as, SO_2 and NO_x out. In order to attempt to link SO_2 and NO_x in emissions trading I will now briefly introduce two studies suggesting voluntary emissions trading for these other pollutants. The first is the report by the NERA Economic Consulting, which was commissioned by the European Commission. The second is the Swedish Shipowners' Associations study on voluntary trading.

The NERA Economic Consulting introduced four different market-based instruments to designed to reduce SO_2 and NO_x emissions from ships. The four approaches introduced were: Credit-Based Approach, Consortium Benchmarking, Environmentally Differentiated Charges and Environmental Subsidy Approach. Out of these four, the first – Credit-Based Approach – most resembles emissions trading reviewed earlier. In this the shipowners could voluntary participate in emissions trading and trade their emissions reduction credits with land-based installations. The second approach – Consortium Benchmarking – also involves emissions trading but in this approach the shipowners would form a consortium and trade among themselves. The last two approaches are not emissions trading, but introduce ways like differentiated port dues based on environmental aspects of the vessel or government subsidies. (Harrison – Radov – Patchett – Klevnas – Lenkoski – Reschke – Foss 2005, ii-vii.)

In the report the NERA consultants could not recommend one approach from another. All had positive and negative attributes and required different actions from both shipowners and regulators. The conclusion was that the programs show promise and they should be studied and developed further. (Harrison et al. 2005, xi-xii.)

Swedish Shipowners' Association also suggests emissions trading for SO_2 and NO_x emissions. Some of the reasons are: a significant amount of these emissions will in the future originate from the shipping industry, there has been success in sulphur emissions trading in the Unites States – program mentioned earlier in this chapter –, and shipping industry can lower these emissions at a lower cost than land-based industries. The Swedish Shipowners Association suggests an emission trading between ships and land-based installations that are under the IPCC Directive[1]. They believe that emissions trading between different operators would allow for cost-effective over-all-reduction of SO_2 and NO_x emissions. They argue that the positive experience from the EU ETS creates a favourable environment to implementing emissions trading for SO_2 and NO_x emissions as well. (Swedish Shipownerss Association 2006, 2-5.)

[1] The Directive 2008/I/EC also known as the IPCC Directive in an environmental directive set to minimize industrial emissions of greenhouse gases, acidifying substances, wastewaters and waste from various sources in the European Union. Around 52 000 installations are included in the directive, each of which is required to obtain environmental permits. (The IPCC Directive.)

2.4 Conclusions

The theory of emissions trading could be described as almost middle-aged, but in practice the different systems around the world are still in their infancy. The systems and regulations of emissions trading vary significantly. The comprehensiveness of the emissions trading system is directly linked to whether it's an international, national or regional program. However, common among all the emissions trading systems is the goal of reducing emissions in a cost-effective way. Introducing a cap-and-trade system allows the polluters to decide for themselves if they want to invest in emission reducing technology or purchase allowances.

Without a doubt, the EU ETS has developed the furthest. But even with the EU ETS it is very hard to evaluate its' effectiveness. First trading period was plagued by over allocation of allowances and trade prices fell to zero long before the first trading period was completed. The beginning of the second trading period, on the other hand, has been dealing with probably the worst economic decline since the Great Depression in the 1930's. The ultimate impact of the current economic situation has yet to be seen. However, it is clear, that the beginning of the second trading period cannot be described as "Business as usual".

The continuous development and inclusion of additional industries in the EU ETS will most likely continue in the near future. The pace of these new developments and changes is rather quick. Whether the fundamentals or the practicalities of the additional industry inclusions into the EU ETS have been thoroughly planned remains to be seen. The fact that no one is certain where the development may lead in the next few years causes anxiety, especially among the industries that are under consideration to be included into the EU ETS system.

Shipping industry will cause significant SO_2 and NO_x emissions in the future. In light of this different instances have suggested voluntary emissions trading for these pollutants, but nothing concrete has yet to be decided.

3 REGULATORY FRAMEWORKD FOR MARITIME ENGINE EMISSIONS AND THE ENGINE EMISSIONS

3.1 International Maritime Organization regulations

3.1.1 *Basic regulatory framework*

International law and State regulations control the worlds' maritime activities. The United Nations Convention on the Law of the Sea (hereafter referred to as UNCLOS) is the main international maritime law. UNCLOS gives the right to create and maintain a ship registers to independent States, and thus become a flag States. UNCLOS requires that the flag States enforce the international maritime law. The ships are also regulated by the laws of their given flag State. It is the flag States responsibility to make sure that ships engaged in international shipping abide by the international conventions. Flag States are also called the 'Contracting Governments' (Second IMO GHG Study 2009, 31.)

50 conventions and protocols – of which 41 are in force – formulated by the IMO, make up the international maritime law. These conventions enter into force as required number of counties representing a set portion of the world's fleet has ratified the convention. In addition to IMO regulations, there are the regulations concerning seafarers created by International Labour Organization (ILO). Figure 3 illustrate the players' active in maritime industry. The red arrows in the Figure 3 portray the channels in which the regulatory framework functions. (Second IMO GHG Study 2009, 31-32.)

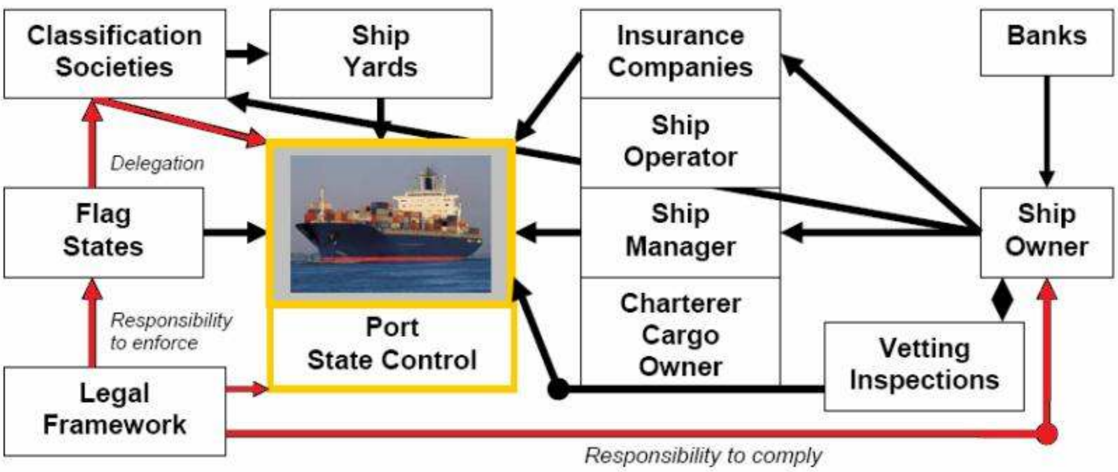

Figure 3 Players of the legislative framework for shipping (Second IMO GHG Study 2009, 31.)

Not only does IMO regulations affect the flat States, but flag States can authorize the classification societies to act on their behalf when conducting technical surveys. Another crucial player illustrated in the Figure is the Port State Control. When an IMO regulation has been ratified by a country and when it enters into force, the Port State Control can enforce the regulation on all the ships in its ports, no matter whether the country of the ship's nationality has ratified the conventions or not. This is in accordance with basic IMO fundamental of 'no more favourable treatment', which means that developed and developing economics are treated equally. The Port State Control may inspect the ship's technical standards and if found lacking, the Port State can prevent the ship from leaving until necessary repairs have been made. (Second IMO GHG Study 2009, 32.)

3.1.2 *Regulatory framework for environmental issues*

Out of the 51 conventions formed by IMO, 21 are entirely concerned with environmental aspects. Most important of which, is the International Convention for the Prevention of Pollution from Ships from 1973. After the amendments made in 1978 the convention became known as MARPOL 73/78. Further amendments and updates have been made since. MARPOL is concerned with pollutants such as: oil, noxious substances, harmful substances, sewage, garbage and air pollutions caused by ships. 99 % of the world's merchant fleet is under MARPOL and it has had significant effect on decreasing pollution. (IMO and the Environment 2009, 2.)

For this study the MARPOL regulations concerning the Prevention of Air Pollution from Ships are relevant. The Prevention of Air Pollution from Ships regulation was added to MARPOL in 1997 and they can be found from Annex VI of the Convention. At the 58th MEPC – IMO's Marine Environment Protection Committee – session in 2008, the regulations were amended in order to make them more stringent. These new regulations concerned especially SO_2 and NO_X emissions. These new amendments to Annex VI will enter into force 1st of July 2010. (Prevention of Air Pollution from Ships.)

In the rest of the Chapter 3.1., the regulations pertaining to SO_2 and NO_X emissions are viewed in detail. In addition the IMO discussions on greenhouse gas emissions – primarily CO_2 emissions – are introduced in this part. As SO_2 and NO_X emissions are actually included in the MARPOL Annex VI, these are viewed first. The CO_2 emissions, however, are not included in MARPOL as of yet, which is why they are viewed second. As CO_2 emissions have been under much discussion at IMO, I feel it is important to introduce the current state of the discussion and the solutions IMO is considering for CO_2 emissions.

3.1.2.1 *MARPOL 73/78 Annex VI Regulations 13 – NO_x*

Regulation 13 of Annex VI is set to control the nitrogen oxide emissions from the use of marine diesel engines with power output of greater than 130 kW. There are strict rules on the emission quantities based on the installation of an engine in a ship. The engines are categorized as TIER I, TIER II and TIER III based on the installation date of the engine. The NO_x emission limits are calculated as total weighted emissions for NO_2. The limits are further separated for different engine revolutions speeds. Table 5 combines the different emission limits for all of the different TIERs. (MARPOL 73/78, Annex VI, regulation 13.)

Table 5 TIER I-III NO_x emission limits for engines (MARPOL Annex VI, Regulation 13)

Regulation	NO_x limit	RPM (n)
TIER I	17 g / kWh $45 * n^{(-0,2)}$ g /kWh 9,8 g / kWh	$n < 130$ $130 \leq n < 2000$ $n \geq 2000$
TIER II	14,4 g / kWh $44 * n^{(-0,23)}$ g / kWh 7,7 g / kWh	$n < 130$ $130 \leq n < 2000$ $n \geq 2000$
TIER III	3,4 g / kWh $9 * n^{(-0,2)}$ g / kWh 2,0 g / kWh	$n < 130$ $130 \leq n < 2000$ $n \geq 2000$

TIER I regulations are applicable to engines installed on a ship constructed on or after 1st of January 2000 but before 1st of January 2011. Whereas, TIER II limits are for engines installed after 1st of January 2011. (MARPOL 73/78, Annex VI, regulation 14.)

The most stringent of the NO_x limits apply to the TIER III engines. These engines are to be installed on ships constructed on or after January 1st 2016. Whereas, TIER I and TIER II limits apply to all ships, TIER III apply to special NO_x emission control areas, which are determined in Appendix III of Annex VI. When ships sail in specified emission control area they are required to apply by TIER III limits and by TIER II limits when sailing elsewhere. A study on technical feasibility of these limits will be completed no later than 2013. (MARPOL 73/78, Annex VI, regulation 13.)

A new emission control area for NO_x was agreed upon at the 60th MEPC Committee meeting. With an amendment to MARPOL that is expected to come into force 1st of August 2011, the North American Emission Control Area was created. The emission control area limits of SO_x and NO_x emissions from ships. (IMO environment Committee makes progress 2010.)

There are also special provisions to ships constructed after 1990 but before 2000 on Annex VI. They apply to engines with power output of at least 5000 kW and a per cylinder displacement above 90 l. More specific details can be found on Annex VI, Regulation 13, paragraphs 7.1. to 7.5. (MARPOL 73/78, Annex VI, regulation 13.)

3.1.2.2 ***MARPOL 73/78 Annex VI Regulation 14 – SO_x***

Regulation 14 of Annex VI of MARPOL regulates the content of sulphur in fuel oil. The reduction of sulphur quantities in fuels is done progressively. The reduction stages are different for the Sulphur Emission Control Areas (hereafter referred to as SECA) and the rest of the world. The SECA is illustrated in Figure 4.

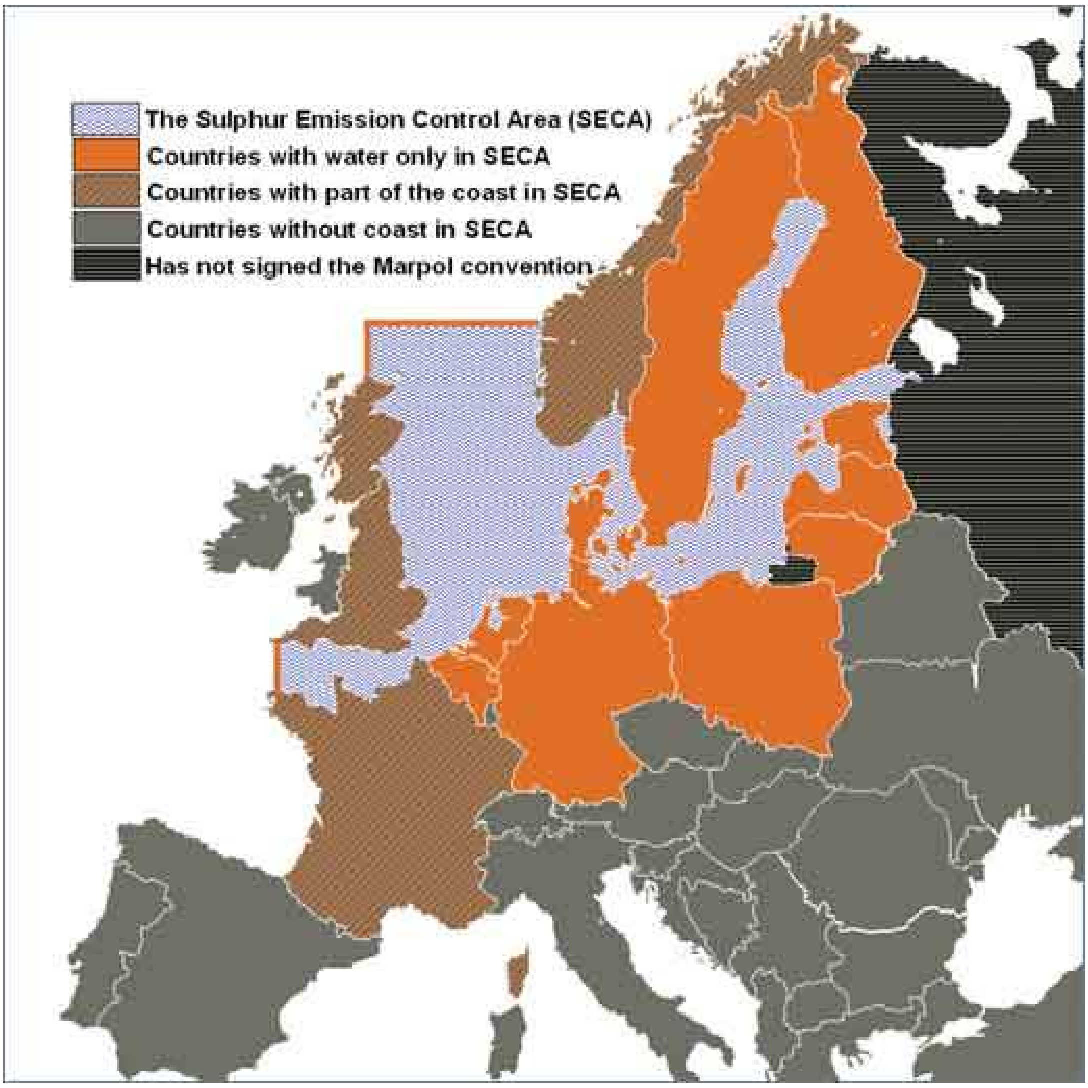

Figure 4 The Sulphur Emission Control Area (Boholm 2010)

Paragraph 3 of Regulation 14 of Annex VI, states that the English Channel, the North Sea and the Baltic Sea are considered to be an emission control areas for sulphur emissions. Figure 4 also illustrates that Russia has not signed the MARPOL convention which means that they are not forced to comply with the regulation. This may lead to severe distortion of logistics flows as well as lead to unfair competition within the area. (Boholm, 2010.)

As said above, the reduction timetables are different for SECA and the rest of the world. Figure 5 depicts both the reduction amount for the fuel sulphur percentage and the timetable in which the planned reductions for both the SECA and the rest of the world are to be made.

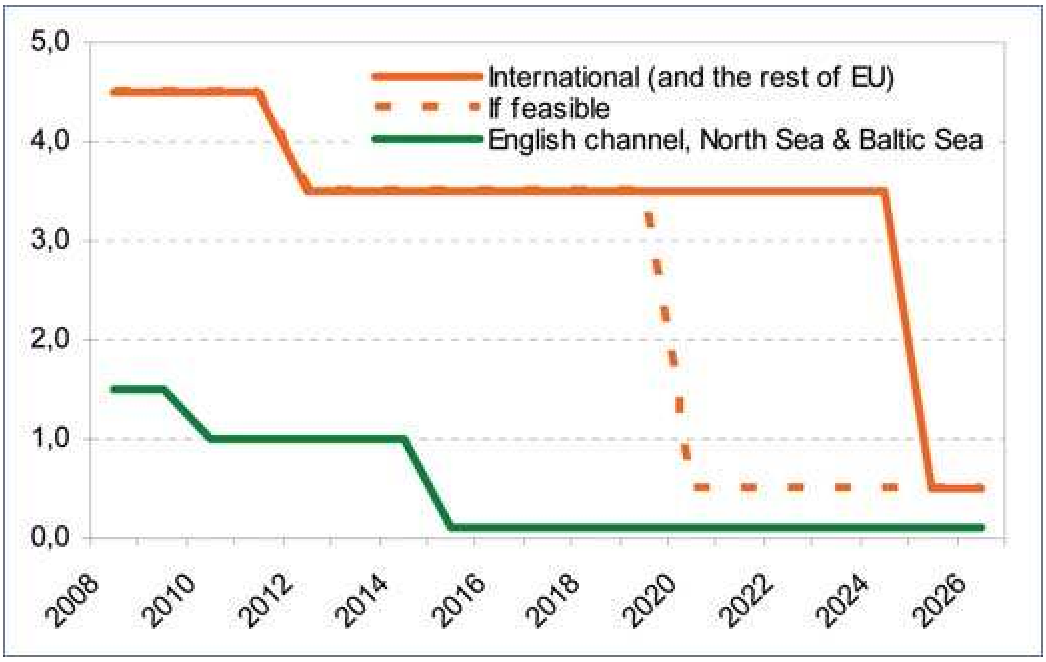

Figure 5 New sulphur limits for fuels for Sulphur Emission Control Area and the rest of the World (Boholm 2010)

The green line in the Figure 5 represents the SECA area and orange line represents the rest of the world. The planned reduction will first take place in the SECA area and two years later the first reduction for international waters is planned.

Paragraph 2 of Annex VI states the actual reductions and dates for the non-SECA areas. The current sulphur limit is 4.5 % m/m. From January 1st 2012 this amount will be reduced to 3.5 % m/m. The next reduction will be made starting from January 1st 2020 and the sulphur content must be 0.5 % m/m. An expert group set up by IMO will complete a feasibility study by 2018, in which they will assess whether this reduction timetable is possible. If the findings from the expert group state that 2020 is not workable, then the deadline for the last reduction will be set for 2025. (MARPOL 73/78, Annex VI, regulation 14.)

The timetable for the SECA area is a lot quicker and a lot more stringent. The first reduction in SECA area will take place on 1st of July 2010. On this date the sulphur content will be reduced from the 1.5 % m/m to 1.0 % m/m. The second reduction comes only four and a half years later, at the beginning of 2015 and the sulphur quantity will drop to 0.1 % m/m. No feasibility study will be made before the final reduction in the SECA areas. (MARPOL 73/78, Annex VI, regulation 14.)

The timetable for the final reduction in SECA has met with strong opposition – especially among Finland and Sweden – as the decision has been made without proper study of the impacts that this stringent regulations has. However, the sulphur regulation will not come into force until the EU has amended its sulphur directive. The European Commission is currently reviewing the impacts the sulphur regulation will have on fuel availability, costs and logistics in general. The Commission will also look at the benefits of the regulation. A public consultation is believed to begin in spring 2010. The amendment to the directive is expected to come out at the end of 2010. (Elinkeinoelämän Keskusliitto 2010.)

3.1.2.3 *IMO technical and operational measures to reduce greenhouse gas emissions*

The IMO currently has no mandatory greenhouse gas emissions regulations, but discussions have been held on the subject for some time and IMO realizes the importance of such regulations. CO_2 is considered to be the most critical, of all the greenhouse gases, in relation to international shipping when the quantity and the global warming effects are considered. CO_2 emissions from international shipping accounted for 2.7 % of the total CO_2 emissions in the world in 2007. (IMO and the Environment 2009, 4.)

The two technical and operational measures IMO is considering are the *Energy Efficiency Design Index* (hereafter referred to as EEDI) and the *Ship Energy Efficiency Management Plan* (hereafter referred to as SEEMP). The EEDI index is designed to assess the energy efficiency of newbuildings and SEEMP is for use in all ships in operation. Even though, progress has been made in both programs, the there are still many details that has to be decided, such as ship size, reduction dates and reduction limits for EEDI. Work with these issues is set to continue in the 61st MEPC Committee meeting in fall of 2010. IMO environment Committee makes progress 2010.)

3.1.2.4 *IMO market-based instruments for greenhouse gas reductions*

IMO recognizes that technical improvements to ship design and energy-efficiency are not enough to combat the greenhouse gas – primarily CO_2 – emissions from ships as the volume of world trade grows. Due to this, market-based instrument has been discussed as an additional means of reducing emissions. The goal is that market-based instruments – for example emissions trading – would create incentives to invest in new technology and, thus, reduce emissions. Discussions on the subject have been held at several MEPC meetings so far. (IMO and the Environment 2009, 4.)

The progress made in the 60th MEPC meeting in March 2010 resulted in a formation of an Expert Group. The goal of this group is to study the proposals submitted to IMO regarding market-based instruments. These proposals are considered based on their feasibility and impact for maritime industry. The subject will be further reviewed at the 61st MEPC meeting in the fall of 2010. (IMO environment Committee makes progress 2010.)

As market-based instruments are still under discussion and study, it is impossible to say what form they will eventually take, or even if IMO is able to come up with a market-based solution for CO_2 emissions at all. The deadline set by the EU to IMO to come up with a solution to CO_2 emissions from ships is at the end of 2011. However, the MEPC committee meets only a few times a year, which means that by the time that the deadline is here, the committee has only had maybe 3 to maximum of 4 meetings. Progress needs to be made quickly or the EU will take action.

3.2 European Union regulations

The inclusion of IMO conventions into EU regulation – as they are – brings considerable added value to the conventions. The adoption of these conventions into EU regulation means that they are enforced across the entire European Union. In addition to this, the EU continues to work towards stricter environmental regulations on the international level. (Maritime Transport Policy 2006. 8.)

An example of the EU implementing IMO convention is Directive 2005/33/EC which is also known as the sulphur directive. The original Directive 1999/32/EC was amended in 2005 with regards to sulphur content in maritime fuels. As well as making the EU regulation uniform with the IMO convention, the EU also made an addition to the directive. This addition requires the ships to use maximum content of sulphur of 0.1 % in fuel when at berth in any port within the EU. The commencement of the requirement is January 1^{st} 2010. (European Maritime Safety Agency.)

3.3 Engine emissions from ships

3.3.1 *Types of engine emissions from ships and emissions included in this study*

The engine emissions from ships are the result of the combustion of fuel in the engine. These emissions can be divided into two categories based on whether they are the result of the combustion process or come directly from the fuel. Pollutants directly related to the combustion process are: carbon monoxide (CO), volatile organic compounds (VOC), particulate matter (PM) and nitrogen oxides (NO_x). Pollutants originating from the fuel are carbon dioxide (CO_2), sulphur oxides (SO_x), heavy metals and additional particulate matters such as sulphates. (EMEP/EEA2009, 8.)

2–5 % of anthropogenic NO_x and 3–4 % of anthropogenic SO_2 emissions are estimated to be generated by international shipping. On national level these emissions can be significantly higher, such as SO_2 emissions ranging from anywhere between 0–80 % of total national SO_2 emissions and NOx ranging between 0–30 %. CO_2 emissions can range from 0–40 %. Other emissions caused by national shipping ranging only between 0–5 % of total national emissions. (EMEP/EEA 2009, 8.)

The *Second IMO GHG Study 2009* (7) estimated that international shipping accounts for 2.7 % of the total CO_2 emissions. There is a significant increase in the estimate since the *IMO GHG Study* from 2000 which estimated that shipping accounted only for 1.8 % of the total CO_2 emissions. The main sources of emissions from ships are the exhaust emissions. CO_2 is the dominant greenhouse gas emission in terms of both quantity and global warming potential. (Second IMO GHG Study 2009, 7.)

The emissions included in this study are CO_2, SO_2 and NO_x. These pollutants are chosen due to their importance and quantity in relation to other emissions from ships. In the next part of this chapter these emissions are reviewed briefly based on their characteristics and effects on the nature.

3.3.1.1 *CO_2*

Carbon dioxide is a natural part of the earth's atmosphere. It can be emitted by natural sources or human activities, mainly burning of fossil fuels. Natural sources of CO_2 are, for example, the respiration of animal, in which oxygen and nutrients are transformed into CO_2 and energy. Whereas, photosynthesis of the plants removes CO_2 form the atmosphere. The oceans also have a part to play in the carbon cycle, they remove and release CO_2 at sea surface. The carbon cycle is in balance when the emissions and removals are roughly the same amount. (U.S. Environmental Protection Agency 2010.)

As CO_2 is a natural part of the atmosphere, it is not considered to be toxic. However, it does have a greenhouse gas – warming – effect on the atmosphere. (Kalli, Alhosalo, Erkkilä, Åkerström & Sundberg 2005, 37.) The last 300 years has seen the increase in the CO_2 amounts due to human activities. Burning of fossil fuels and cutting down forests increases the amount of amount of CO_2 in the atmosphere. The levels are now 35 % higher than what they were before the Industrial Revolution of the 1700's. (U.S. Environmental Protection Agency 2010.)

Another factor that has to be taken into consideration when talking about CO_2 emissions is, that it remains in the earth's atmosphere for very long time – centuries to millennia – after it has been emitted. Thus, continuing to have warming effect long after it was emitted. (Second IMO GHG Study 2009, 16.)

3.3.1.2 ***SO_2***

Sulphur oxides (SO_x) from international shipping are the result of burning fossil fuels. The sulphur that is present in the fuel will be emitted as sulphur oxides – primarily sulphur dioxide SO_2 – in full. (Second IMO GHG study 2009, 245.)

Sulphur in the fuel mixes well with water. As sulphur is released into the air, it mixes with water and forms sulphuric acid. It does not matter where these emissions are emitted, as they can travel for thousands of kilometers. These emissions cause acid rains and when absorbed into the earth, cause acidification of the soil and water systems. (Kalli et al. 2005, 33.)

3.3.1.3 ***NO_x***

Anthropogenic sources of nitrogen oxides: nitrogen monoxide and nitrogen dioxide – known together as nitrogen oxides – are the result of the combustion process. (Kalli et al. 2005, 34.) The NO_x emissions from diesel engines are rather high if not controlled. The formation of NO_x emissions during combustion is directly related to the temperature and the chemical process of NO_x formation is very complex. (Tuuf 2009, 4.)

The environmental impacts of NO_x emissions are, for example, acid rains, over-fertilization and ozone and smog generation in the lower atmosphere, which is harmful for the human health and vegetation. (Tuuf 2009, 7.)

3.4 Factors affecting engine emissions included in this study

In this part of the study some of the factors that affect the engine exhaust emissions are introduced. These are by no means the only factors that affect the quantity and quality of the emissions. However, these factors are taken into consideration in this study since they affect the emissions calculated by mathematical equations used in this study. These equations are presented in detail in Chapter 5.

3.4.1 *Diesel Engine categories*

Emissions from ships depend on different factors. One of the factors that affect the ship's emissions is the engine type. The main types of diesel engines are now reviewed briefly, in order to illustrate the effects the engine type has on the emissions.

The inclusion of diesel engine in this study and exclusion of other types, such as, steam turbines and gas turbines has been made, because diesel engines are the main power providers in marine transportation industry. Propulsion and auxiliary power are both being provided by diesel engines. According to EMEP/EEA (2009, 7) an analysis of 30 000 ships stated that 95 % of the world's fleet was powered by diesel engines. Wijnolst and Wergeland (2009, 658) concluded that the world fleet consisted of 103 476 ships in April of 2008. 56 % of these were powered by heavy fuel oil direct engines and 38 % by diesel burning geared drive engines.

Engine types are usually categorized by their revolution speed. Revolution speeds are classified as slow, medium and high. Engines are almost exclusively either slow or medium speed engines in maritime industry, which is why high speed engines are excluded from this study.

3.4.1.1 *Slow Speed Diesel Engine*

The definitions of revolution speeds vary in what constitutes a slow speed engine. Generally accepted definition is that slow speed engines are those that have a revolution speed of less than 300 revolutions per minute (rpm). Usually speeds significantly lower than 300 rpm are seen in operation when talking about low speed engines. Most of the slow speed engines are 2-stroke, cross head engines with 4-12 cylinders. Slow speed engines are used for powering the propulsion of the ship. (EMEP/EEA 2009, 7.)

The 2-stroke engine gets its' name from the number of up and down motions the piston has to make in order to create power. Figure 6 has a detailed illustration of the 2-stroke engine. The first picture illustrates (on the left side of Figure 6) the engine releasing exhaust air and intake of new air. The crankshaft rotates in clockwise direction. In the second picture the engine's piston is moving up in the cylinder, which creates pressure and the air temperature rises. When the piston reaches the top, fuel is injected into the cylinder (picture 3). Injecting the fuel creates a chemical reaction between the fuel and the hot, pressurized air, which in turn force the piston to move down. The stage presented in picture 3 is the only one where work energy is put into the engine. In other stages of the combustion cycle the engine has to do the work. (The Basics: The 2 stroke diesel cycle.)

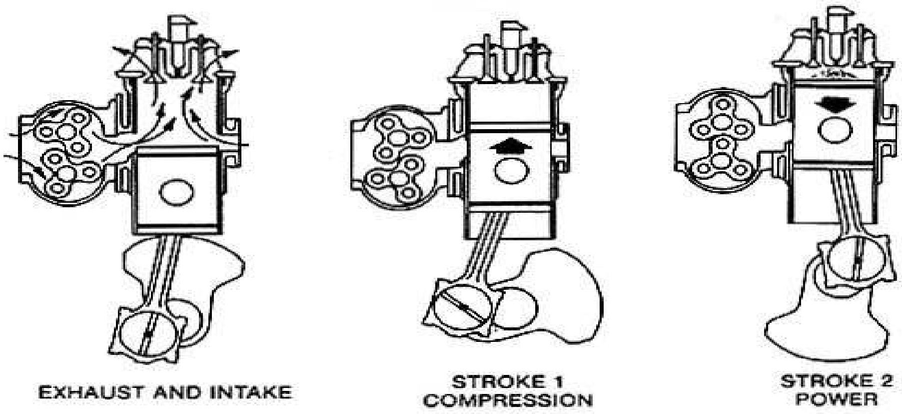

Figure 6 The cycles of a 2-stroke engine (The Marine Diesel Engine. Part One: The Two Stroke)

Large ocean-going ships almost solely use slow speed engines. These slow speed engines are very suitable for this type of cruising, long distances at steady speed. The engines are usually connected directly to the propeller shaft. This means that the propeller and engine have the same revolution speed and the ship has no gear-box. These ships usually also have fixed propellers. Due to these properties and the large size of this type of ships; tug assistance is almost always required in port manoeuvering. (Wijnolst and Wergeland 2009, 661-663.)

Slow speed engines are the best in regard of energy-efficiency. These engines are able to use residual oils to create combustion in the engine. Residual oils are cheapest and since large ships use large quantities of bunkers, it is more economic to use residual oils than cleaner oil products such as Marine Diesel Oil or Marine Gas Oil. However large engines in large ships create less airborne emissions than small engines on small ships. (Wijnolst and Wergeland 2009, 658-663.)

3.4.1.2 *Medium Speed Diesel Engine*

Engines with 300-900 rpm are considered to be medium speed engines. They are mainly 4-stroke trunk piston engines that have either up to 12 cylinders in line or 20 cylinders in 'V' formations. Medium speed 4-stroke engines can be used as main propulsion power or auxiliary power. Large ocean-going ships use this type of engines as auxiliary power, such as electricity provider. Whereas, smaller ships have 4-stroke, medium speed engines as main propulsion engine. In this case, the engine is almost exclusively connected to the propeller shaft via gear-box, so that the engine revolutions are not the same as the propeller revolutions. (EMEP/EEA 2009, 7.)

The 2-stroke engine got its' name from the 2 movements the piston makes, up and down. The same logic applies to the 4-stroke engine. The piston has to make 4 movements, 2 ups and 2 downs, which results in the crankshaft revolving clockwise 2 times. Figure 7 shows the stages of a 4-stroke engine. Again from left to right, the first stroke has the piston going down and air pushed into the cylinder. The second stroke is the same as in 2-stroke engine; the piston is going up and the air is being heated and pressurized. The third stroke again is the same as in the 2-stroke engine. The fuel is injected into the cylinder when the piston reaches the top and the chemical reaction forces the piston down. And just like in the 2-stroke engine this is the only stage of the engine cycle that has work energy being put into the engine. Other states the engine has to do the work. In the final stage of the 4-stroke engine the piston is once more moving up and at the same time pushing the exhaust gas out of the cylinder. (The Basics: The 4 Stroke Diesel Cycle.)

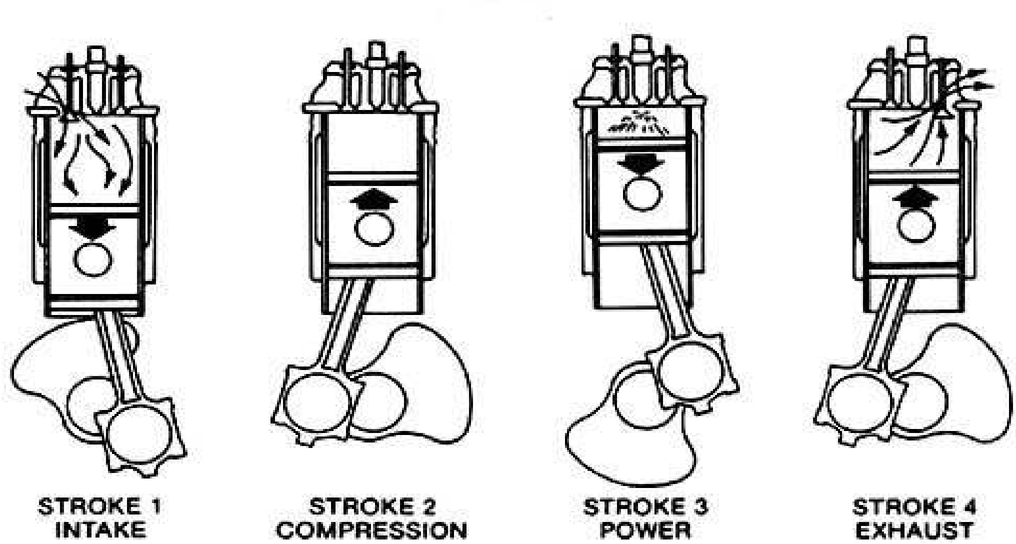

Figure 7 The strokes of a 4-stroke engine (The Marine Diesel Engine. Part Two: The Four Stroke Engine)

3.4.2 *Fuel qualities*

The main categories of marine fuels are residual and distillates fuels. Residual oil is what remains when all the volatile components are taken out of the crude petroleum. These volatile components are for example kerosene, gasoline, diesel and naphtha. In other words, residual oil is the waste that is left. The residual oil is the dirtiest kind of oil there is. The price of residual fuel is lower than crude oil. (Kendall and Buckley, 2001, 184.)

Residual fuels and distillate fuels are often mixed together to form fuels with different qualities. Different specifications of fuel qualities have been standardized by for example by International Organization for Standardization (ISO). (Kendall and Buckley, 2001, 185.) The ISO 8217 Fuel Standard, newest and third edition from 2005, specifies, for example, fuel properties such as density and viscosity.

When evaluating the fuel, Kendall and Buckley (2001,186) add energy content together with density and viscosity. Density is the factor that is needed to compute volume to mass. Bunker is always delivered in cubic meters but priced in tonnes. In order to do that, the fuel density is needed. Density also varies at different temperatures, so a standard temperature of 15 degrees Celsius has been adopted for the conversion. Viscosity, on the other hand, measures the fuel's resistance to flow. For viscosity, a standard temperature has also been adopted for sales purposes. Heavier fuels – residual fuels – need to be heated in order to get them to flow. Energy content creates the power that moves the ship. It is measured by calorific value and it is related to fuel density. Dense fuel has more carbon and less hydrogen in proportion than light fuel. Dense fuel will release less energy per kilogram than lighter density fuel.

Different names for same quality and technical aspects of the fuel are used depending on for example location. The Americans use the ASTM D975 standard, and they use No.1 D – 4 D, Sxxxx, x corresponding to sulphur content. ISO 8217 uses DMX, DMA, DMB, DMC where D refers to distillate, M to marine and the last letter specifies the quality. ISO also uses RM, where R is residual and M marine. This is then followed by a third letter, just like in distillate fuels, which represents different specifics of the fuel. For bunker sales and purchases purposes different names are used. They are MGO (Marine Gas Oil), MDO (Marine Diesel Oil) IFO (Intermediate Fuel Oil), MFO (Medium Fuel Oil) and HFO (Heavy Fuel Oil). The names refer to different types of pure or blended oils. MGO is pure gas oil, whereas, HFO is pure residual oil and the rest are all blends. (Diesel Fuel Grades; ISO 8217 Fuel Standard)

For the purposes of this study distinction will only be made between HFO and MDO/MGO fuel qualities.

4 METHODOLOGY AND EXECUTION OF STUDY

4.1 Research design

The aim of this study is to assess the financial impacts of emissions trading for shipowners. For this purpose the following research design was created. Different parts of the research can be seen in the flowchart in Figure 8. The flowchart also illustrates the sequence of the research parts.

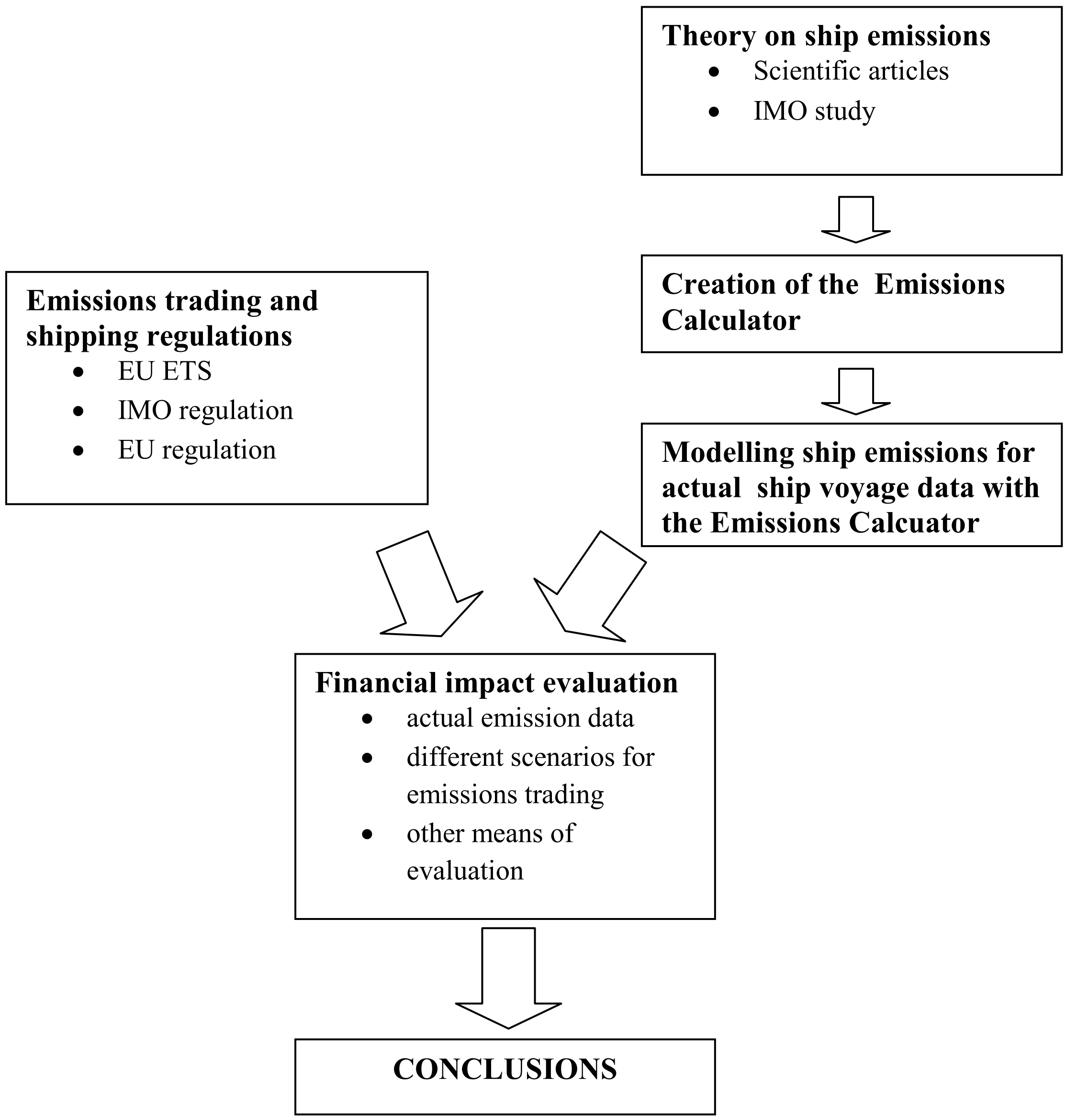

Figure 8 Flowchart of the research design

First part of the research was to review the current European Union Emissions Trading Scheme and the international regulations that control the emissions from international shipping. Especially important for this study, is the inclusion of aviation industry into EU ETS, since it may bear resemblance to the possible inclusion of shipping industry as well.

The second part in the study is to look at the theoretical models for evaluating the ship's emissions based on mathematical models. This is a very important part of the study, because the emission evaluation models found in scientific articles would be the basis of emission quantity estimation for this study as well.

The creating of an emission calculator – the *Marine Emissions Evaluator* –, specifically for this study is the third task. The emission calculator must be comparable with the current scientific views on mathematically evaluating emissions from ships, in order to gain relevant data out of the calculator.

In the next part of the study, the emissions calculator is used to estimate the actual emissions from a typical dry cargo vessel active in trade in the Baltic Sea and the North Sea. The authentic vessel voyage data was received from a ship operating company in Finland.

Part five brings the regulatory framework, the emissions trading and the ship emissions together to evaluate the financial impact for the shipowners. For evaluating the financial impacts different possibility scenarios are created. The probabilities of these scenarios are not assess, only the financial impacts each would have for the shipowner.

In the final part of the research the findings are compiled together and conclusions are made.

4.2 Literature review

The information quantity related to emissions trading and ship emissions are astounding. The problem was to find the information and sources that were both reliable and current. The source literature used in this study can be divided into two categories. The categories and the most important source literature – especially for evaluating ship emissions – are now summarized briefly.

First category is the information gathered from official sources, such as, from the European Union and the IMO Internet pages. This information comes in form of Directives, official publications and press releases. In order to guarantee that the information was up-to-date, an attempt was made to gather the newest possible information from these sources. The basic assumption that was made when utilizing these information sources was that the information provided was actually both reliable and correct.

The second category of relevant source information is the literature relating to estimating ship emissions. For this category the amount of information available was never-ending. The problem was to find sources that provided clear and precise tools for estimating ship emissions for single vessels instead of the world's entire fleet. Significant numbers of ship emission studies are modeling the emissions for the entire fleet. The source literature also had to be consistent with each other in order to maintain the validity of the study.

As the primary source for the ship emissions, the *Second IMO GHG Study 2009* was chosen. This is due to the fact that the IMO study is one of the most comprehensive studies on the subject and it is used as a reference source in many other ship emission studies. *The EMEP/EEA air pollutant emission inventory guidebook – 2009* has also been as a fundamental guide to ship emissions. Even though, both of these sources are considered to belong to the second category, they could also belong to the first category as well, since they are both published by official sources: first one by IMO and the second one by the European Environment Agency (EEA), which is an agency of the European Union.

As far as scientific articles go, several studies published by Psaraftis and Kontovas from National Technical University of Athens are used as source literature in this study. Their methods of evaluating emissions from ships are similar to those used in the IMO study. More about the studies by Psaraftis and Kontovas is presented later in chapter 5.

4.3 Reliability and validity of the study

As the tools for estimating emissions from ships are very similar in the main reference studies, the results of this study on the emissions quantity would be similar to that of another study, given that similar ship characteristics are used. Based on the fact that the mathematical estimations of emission evaluation are so similar in main reference studies, any researcher would receive similar emissions quantity results should they use the same ship activity data or indeed even a different ship with similar characteristics. Thus, the reliability of the study in relation to ship emissions based on mathematical emissions modeling is sufficient. Differences would most likely occur if it was possible to measure the actual emissions onboard the ship used in this study. This is due to the fact that mathematical modeling has to use averages and generalized factors derived from the world's entire fleet. This may lead to variations between mathematical modeling results and results gained with onboard measuring. However, the mathematical emissions modeling is believed to provide sufficiently accurate enough information about the emissions quantities that the financial implications can be assessed based on the emissions estimated, without actually going onboard and measuring the emissions in practice.

The differences that may affect the reliability of the study would most likely occur in the financial impact evaluation. The methodology chosen for the evaluation of financial impact will greatly influence the results. Since there is no way of precisely knowing the way in which the financial impacts of emissions are likely to affect shipping in the near future, there are different ways of estimating the financial impacts. However, if emissions trading in the European Union were chosen as the method, the results would be comparable to that of this study.

The validity of this is study improved by the use of real voyage data for a ship in active trade received from a ship operating company in Finland. This ship represents a typical dry cargo or general cargo vessel active especially in the Baltic Sea. Based on this data, generalization is made to ships with similar characteristics and trade use. The emission evaluation based on this ships' voyage information is believed to be parallel to that of ships with similar characteristics and size. Thus, the results of the financial impact evaluation would include not only the ship used in the study, but ships that are similar in characteristics and trading patterns to the ship used in this study.

The validity is further improved by using ship specific data on factors that affect the emission quantities. Different engine sizes and types have different emissions factors and using emissions factors that corresponds to the engine onboard the ship, the validity of the results is greatly improved. The same thing is accurate with other ship specific factors as well. These are, for example, the fuel type and fuel sulphur content. When these factors are taken into consideration in modeling of emissions, the accuracy of the results is better and the validity and the reliability of the study are enhanced.

5 QUANTIFYING EMISSONS FROM SHIPS

In this chapter I will concentrate on quantifying CO_2, SO_2 and NO_x emissions from ships. First fuel based emission factors will be introduced. After the introduction of emission factors the actual quantification of the emissions can be made. In order to help in this task, emissions calculator called *Marine Emissions Evaluator* was created, which will be presented in detail at the end of this chapter.

5.1 Fuel-based Emission factors

Emission factors used in this study are all based on fuel consumption. This means that all the emissions results are somehow derived from the ship's consumption of fuel. Even though fuel consumption is the main input in the calculations, different factors still affect the quantity of the emissions. These emission factors are now explained in detail in order to calculate the emissions based on fuel.

Even though fuel consumption is the base of the emissions calculations in this study, calculating fuel consumption based on ship details is omitted here and fuel consumption of a ship is considered known. For further reading regarding calculations of fuel consumption based on ship's GT (Gross Tonnage) see, for example, Trozzi and Vaccaro 2000 or the update of the same study 2006.

5.1.1 *CO_2 Emission factor*

There are several scientific studies on ship emissions, and they utilize slightly different variations of CO_2 emission factors. However, these emission factors vary within a very small margin. Psaraftis and Kontovas (2009, 5) summarized the different factors that are used in emission calculations. Psaraftis and Kontovas have used the empirical mean value for CO_2 emission factor that is frequently used when estimating emissions. This fuel consumption based emission factor uses, as the input, the total fuel consumption in tonnes per day, which is then multiplied by the emission factor 3.17 in order to compute the total emissions in tonnes per day.

The original IMO *Greenhouse Gas emissions from ships*-study of 2000 had CO_2 emission factors ranging from low value of 3.129 to high value of 3.175. The update of the same study, *Second IMO GHG Study 2009* uses even lower emission factors. In the second IMO study, the emission factors for HFO and MGO are also differentiated. The emission factor for HFO is 3.021 and for MGO and MDO the factor is 3.082. Argument has been made by the Working Group on Greenhouse Gas Emissions from Ships –

which is an IMO working group – (see Psaraftis and Kontovas 2009, 5) that the emissions factors used by IMO should be in accordance with the emission factors used by the IPCC (Intergovernmental Panel On Climate Change). This is to ensure that the CO_2 emission factors that IMO applies are in harmony with other parties in the UNFCCC and the Kioto Protocol. (Psaraftis and Kontovas 2009, 5.)

The CO_2 emissions factors that are used in the emissions calculations of this study will be consistent with the Second IMO GHG study 2009. This is due to the fact that they are most recent, even though not yet as widely used as the CO_2 emission factor of 3.17, which is used in several studies. The emissions will be further divided based on the two different fuel types: HFO and MDO or MGO. HFO will have CO_2 emission factor of 3.021 and MDO or MGO will have an emission factor of 3.082. Input of fuel consumption in tonnes will provide an estimate for the CO_2 emissions.

Equation 1 Total CO_2 Emissions in tonnes

$$CO_2\,E = FC * EF;\ \text{fuel type}$$

where;

CO_2 E	Total CO_2 emissions in tonnes
FC	Total fuel consumption in tonnes
EF; fuel type	Emission factor based on fuel type (HFO or MDO/MGO)

If the main engine and auxiliary engine use different types of fuel, it must be taken into account when calculating the total CO_2 emissions. Because HFO and MDO/MGO have different emission factors for CO_2 there must be sufficient fuel consumption data for all types of fuels used. Then calculation must be done separately for each type of fuel. Adding the results together will provide the total CO_2 emissions for that particular voyage or ship.

Emission amounts in relation to cargo carried are very interesting. Once we have the total CO_2 emissions calculated with the previous equation it is very straightforward to compute the emissions per cargo tonne. The whole voyage and the laden leg of the voyage can be separated when calculating the emissions per cargo, if sufficient fuel consumption data available. Consumption must be divided into the possible ballast leg of the voyage and the laden leg of the voyage. The emissions per cargo tonne for the whole voyage can be calculated with the following equation.

Equation 2 CO_2 Emissions in relation to cargo quantity

$$CO_2\ E/C = \frac{CO_2\ E}{CQ}$$

where;

CO_2 E/C	CO_2 Emissions tonnes in relation to cargo quantity
CO_2 E	Total CO_2 emissions in tonnes
CQ	Total carried cargo quantity in tonnes

If information about the CO_2 emissions per day is needed, it is very simple to calculate. It is almost the same equation as presented above for CO_2 emissions in relation to cargo quantity. Just substitute the CQ in the denominator with days and the result will be CO_2 emissions per day instead. However, emission quantities vary greatly whether the ship is at sea or in a port and if this is not taken into consideration, the emission calculations may quite likely be incorrect. In order to correct this, the sea and port times must be calculated separately.

5.1.2 ***SO_2 Emission factor***

The SO_2 emissions are only and directly related to the fuel and more specifically the sulphur content of the fuel (Kontovas and Psaraftis 2009, 4). The engine type has no affect on SO_2 emission quantities. However, engine fuel efficiency has an effect on SO_2 emissions, the more fuel efficient the engine is, the lower the SO_2 emissions are, due to the fact that more energy has been extracted from smaller quantity of fuel. All of the sulphur that is present in the fuel will be transformed into sulphur oxides. The equation for calculating SO_2 emissions can be seen below.

Equation 3 Total SO_2 Emissions in kg per tonne of fuel

$$SO_2\ E = FC * 20 * S\%$$

where;

SO_2 E	Total SO_2 emissions in kg
FC	Total fuel consumption in tonnes
S%	Sulphur content in fuel in percentage

Multiplier ‘20’ in the equation is the result of the chemical reaction of sulphur with oxygen. This value is exact and does not change even if the sulphur content of the fuel varies. (Psaraftis and Kontovas 2008, 10.) In order to get the emissions in tonnes per tonnes of fuel, the multiplier 20 must be divided by 1000 which gives us the chemical reaction multiplier of 0.02.

Because this study is limited to the North European SECA areas; the sulphur contents in the fuel are considered to be 1.5 %, 1.0% and 0.1% and the higher sulphur content fuels are not taken into consideration. (see MARPOL regulations in chapter 3).

SO_2 emission quantities can additionally be calculated in relation to cargo and voyage duration. The SO_2 emissions per cargo quantity can be calculated with the equation below. The result unit of the equation is dependent on the multiplier used when calculating total SO_2 emissions. If multiplier in the equation above is 20; the result will be in kg per cargo tonnes. Whereas, if the multiplier is 0.02, the results of the below equation will be in tonnes per cargo tonnes. However, it is advisable to use unit kg in calculating emissions per cargo tonne, because otherwise the results may be presented with excessive amount of decimals.

Equation 4 SO_2 Emissions in relation to cargo quantity

$$SO_2\ E/C = \frac{SO_2\ E}{CQ}$$

where;

SO_2 E/C	SO_2 Emissions kg in relation to cargo quantity
SO_2 E	Total SO_2 emissions in kg
CQ	Total carried cargo quantity in tonnes

The same logic applies to calculating the SO_2 emissions per day, as it did when calculating CO_2 emissions per day, which was introduced in the part 5.3.1.

5.1.3 *NO_X Emission factor*

Nitrogen oxides form in the combustion process of the engine. The precursors to the formation are nitrogen and oxygen. 99 % of the air intake of the engine is made up with nitrogen and oxygen. Most of the oxygen will be utilized during the combustion process of the engine. Whereas, the nitrogen will stay mainly unchanged during the combustion process, except for small proportion, which will oxidize and form different nitrogen oxides, NO and NO_2. The high combustion temperature along with exposure time affects the nitrogen and oxygen formation into nitrogen oxides. Namely this means that the higher the temperature in the combustion cylinder, the greater number of nitrogen oxides are formed. Slow speed engines usually have greater amount of nitrogen oxide formation than medium or high speed engines. (MEPC 58/23/ Add.1 2008, 51.)

The reason that slow speed engines have greater nitrogen oxides formation leads to a situation where we need different emission factors for different engine types that are used in the calculations. Also the regulation in MARPOL Annex VI, Regulation 13. – which is detailed in chapter 3. – requires the use of different emission factors for engines that are pre-2000 and post-2000. The post-2000 engines must meet the MARPOL regulations for TIER I engines. Pre-2000 engines will be called TIER 0 engines. TIER II engines are excluded from the calculations because that regulation is not yet in force. Lloyd's Register has been used in the Second IMO GHG Study (2009, 57) to calculate weighted average factors for world fleet both pre- and post 2000.

The Second IMO GHG Study 2009 does not differentiate NO_x emissions for different loads of the ship's engine. In this study two different stages of operation will be considered: steady cruising for which the emission factors from *Second IMO GHG Study 2009* will be used, and hotelling i.e. berthing in port or anchoring. Emission factors for the hotelling are calculated according to *Methodologies for Estimating Air Pollutant Emissions from Ships* by Trozzi and Vaccaro. The study by Trozzi and Vaccaro actually makes distinction between three stages of operation. These are cruising, manoeuvring and hotelling. However, the difference between the cruising and manoeuvring is not significant and, thus, it will be omitted in this study. The emission factor for hotelling will be formulated from the *Second IMO GHG study 2009* factors according to the principles introduced in the Trozzi and Vaccaro's (1998, 18) study. The emission factor for hotelling stage is 41 per cent from the emission factor for cruising emission factor. Below are the equations for calculating these emissions. First equation is the cruising emissions and the second equation is the hotelling emissions.

Equation 5 NO_x Emissions in kg for cruising

NO_x E; cruising = FC; cruising * EF; engine TIER; rpm

where;

NO_x E; cruising	Total NO_x emissions in kg while cruising
FC; cruising	Total fuel consumption tonnes while in cruising stage
EF; engine type; rpm	Emission factor for cruising based on engine TIER and rpm speed

Equation 6 NO_x emissions in kg for hotelling

$$NO_x\ E;\ hotelling = FC;\ hotelling * (0{,}41 * EF;\ engine\ TIER;\ rpm)$$

where;

NO_x E; hotelling	Total NO_x emissions in kg while hotelling
FC; hotelling	Total fuel consumption in tonnes while in hotelling stage
EF; engine type; speed	Emission factor for cruising based on engine TIER and rpm speed

Fuel consumption is dependent on the ship and the operation in which the ship is in. However, ship owners almost exclusively have very accurate information about the fuel consumption of their ships. Multiplying known fuel consumption amount, in tonnes, with the appropriate emission factor (Table 6 and Table 7) and the total NO_x emissions are received.

Table 6 NOx emission factors for cruising (Second IMO GHG Study 2009, 57)

	Slow speed engine	Medium speed engine
TIER 0 average NO_x factor (kg/ tonne of fuel)	89.5	59.6
TIER 1 average NO_x factor (kg/ tonne of fuel)	78.2	51.4

Table 7 NO_x emission factors for hotelling

	Slow speed engine	Medium speed engine
TIER 0 average NO_x factor (kg/ tonne of fuel)	36.7	24.4
TIER 1 average NO_x factor (kg/ tonne of fuel)	32.1	21.1

Similarly to CO_2 and SO_2 calculations, NO_x emissions can be transformed without difficulties to emissions in relation to cargo quantity or emissions in relation to duration in days. Below is the formula for calculating NO_x emissions in relation to cargo quantity. However, notice must be paid to the fact that, the results of previous equations which are added together in the numerator are given in the unit kg. This leads to our result unit of NO_x E/C equation to be in kg per tonne transported.

Equation 7 NO_x emissions in kg in relation to cargo quantity

$$NO_x\ E/C = \frac{E;\ cruising + E;\ hotelling}{CQ}$$

where;

NO_x E/C	NO_x Emissions kg in relation to cargo quantity
CQ	Total carried cargo quantity in tonnes

When computing the emissions per day, the only thing that has to be done is substitute the cargo quantity in the denominator with total duration of the voyage in days. This provides the NO_x emissions per day. But just like in the CO_2 and SO_2 calculations, the equation will average the NO_x emissions per day and not present accurate quantity if distinction is not made between times at sea and time in port.

5.2 Introduction of two emissions calculators

5.2.1 *NTUA Ship Emissions calculator*

Psaraftis and Kontovas (Psaraftis and Kontovas 2008; Kontovas and Psaraftis 2009) from the National Technical University of Athens, Laboratory for Maritime Transportation have created a *Ship Emissions Calculator* for the Hellenic Chamber of Shipping (available online at address: http://www.martrans.org/emis/) that will be introduced now. The reason for introducing the calculator in detail is that it has been used as a reference model for the emissions calculator that was created for this study, the *Marine Emissions Evaluator*. Even though these two calculators are similar, they are by no means identical. Different emissions factors have been used to calculate emissions. Emissions factors used in the *Marine Emissions Evaluator* have been explained in greater detail before, emissions factors that are used in the NTUA *Ship Emissions Calculator* will now be introduced shortly.

The *Ship Emissions Calculator* computes the emissions in relation to tonne-km, however, the total emissions can also be found from the calculator. Basic assumption of the *Ship Emissions Calculator* is that a ship sails between ports A and B, always in laden condition the other leg and in ballast condition the other leg. The distance in km of port A and port B is L. The speed at which the ship sails while laden is V (km/day) and while in ballast v (km/day). The ship also spends time at each port, which are marked with T for loading at port A and t for discharging at port B. These are both measured in days. The ship is also assumed to be carrying a payload of W on the laden leg of the voyage. (Psaraftis and Kontovas 2008, 11.)

The fuel consumption is assumed known and is measured in tonnes per day. The indicators for fuel consumption are: F for laden at sea and f for ballast at sea. Additionally the consumption at loading port is G and in discharging port g. Psaraftis and Kontovas (2008, 11) also briefly mentions two different ways of calculating fuel consumption, which are used to calculate fuel consumption when it is not known.

So, the variables used when calculating the emissions are L, V, v, T, t, G, g, F and f. From which Psaraftis and Kontovas have calculated the following results:

Transit time from A to B (days): L/V
Transit time from A to B (days): L/v
Total fuel consumption per round trip (tonnes): GT+FL/V+gt+fL/v
Total tonne-km's carried per round-trip: WL
Total CO_2 produced in this round trip: 3,17(GT+FL/V+gt+fL/v)
CO_2 per tonne-km for this round trip: 3,17(GT+FL/V+gt+fL/v)WL = 3,17[(GT+gt)/L+F/V+f/v]/W

From above you can see the formulas for calculating CO_2 emissions. The logic for computing emissions for SO_2 and NO_x are the same, just substitute emission factor with relevant factor for each emission type. The emissions factor for CO_2 in the NTUA *Ship Emissions Calculator* is 3.17, which they argue is used in most studies, but at the same time state that the Second IMO GHG study 2009 uses lower emissions factors and also separate factor for HFO and MDO/MGO (Kontovas and Psaraftis 2009, 3.)

The emission factor for SO_2 in the Ship Emission Calculator is exactly the same as presented earlier in this chapter. In the last two equations above substitute the multiplier for CO_2 with multipliers for SO_2. The equations are multiplied with the sulphur content in the fuel and the chemical reaction multiplier 20 for kg of emissions per tonne of fuel or 0.02 for tonne of emissions per tonne of fuel.

The NO_x emissions are dependent on the engine, just like explained earlier in this chapter. However, there are four emission factor multipliers for different types of engines used in this study and in the *Marine Emissions Evaluator*, whereas, two emission factors are used in the NTUA *Ship Emissions Calculator*. Emission factors in the *Ship Emissions Calculator* are differentiated for slow speed engine and medium speed engine. Emission factor for former is 0.087 and the latter 0.057. The unit in which the results are shown with these factors is: emissions in tonnes per day per fuel in tonnes per day.

In the NTUA *Ship Emissions Calculator*, there are several different ship types that you can choose from. The user can also specify ship details as he chooses. Different ship types also have different size possibilities to choose from. There are pre-specified ports inserted in the *Ship Emissions Calculator*, these are linked to the vessel and size choice. In general the vessels are on the large size and the ports are long distances apart. These pre-specified scenarios are based on actual ships and their typical routes. The data was collected from the members of the Hellenic Chamber of Shipping. (Kontovas and Psaraftis 2009, 4.)

The Figure 9 below shows what the NTUA *Ship Emissions Calculator* looks like. Before emissions can be calculated, information must be filled in to the ‘Vessel details’ and ‘Operational details’. If the user wants to enter his own details, he must choose ‘Enter own details’ from the ‘Select ship type’ dropdown menu. The *Ship Emissions Calculator* then allows you to choose the engine type, payload and trip distance. Then the user must fill in the ‘Operational details’ of the voyage. The trip duration cannot be filled in directly; it is the function of the distance and speed. The user must also fill in the fuel consumption and the sulphur content of the fuel. Consumption is specified separately for fuel oil and diesel oil.

The *Ship Emissions Calculator* is able to compute the emissions once all the relevant information is filled in. Different emission details are detailed based on tonnes transported, tonne-mile and in tonne-km. The calculator does not automatically show the detailed summary below but it can be made visible by pressing the ‘Show/Hide detailed results’ button.

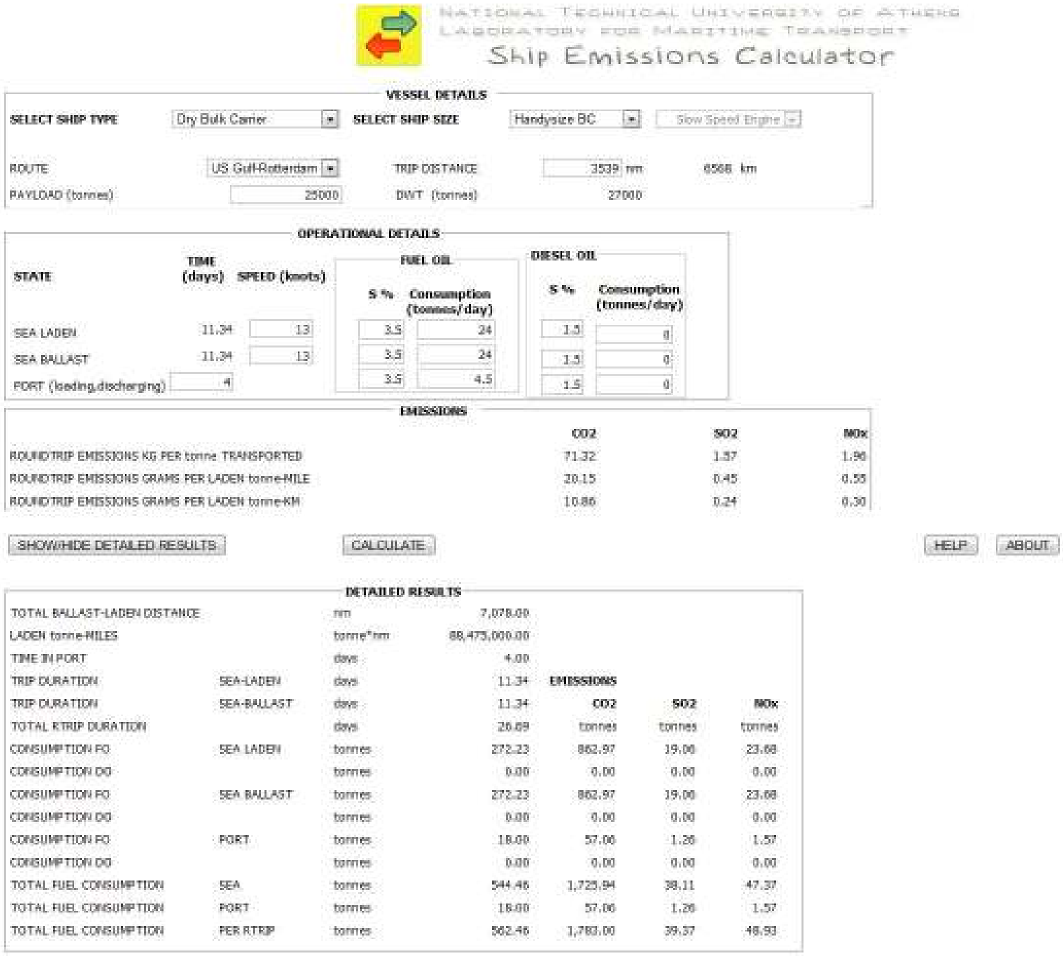

Figure 9 National Technical University of Athens – Ship Emissions Calculator

Wiljolst and Wergeland (2009, 686) also introduce the NTUA *Ship Emissions Calculator* in their book when they talk about sustainable shipping and emissions.

> *A recent study from the National University of Technology of Athens for the Hellenic Chamber of Shipping provides not only a sound methodology for the calculation of emissions from shipping, but also applies it to the entire world fleet.*

In my opinion, the problem with the NTUA *Ship Emission Calculator* is the fact that it only allows for situations where the ship sails between 2 ports that are a given distance apart, which is not always the case with shipping operations. Psaraftis and Kontovas (2009, 4) make a reference to this and states that this is indeed not the only scenario, but it is seen in charter market and especially in tanker trades. The problem incurs when the user tries to apply the emissions calculator for a smaller scale ships than the ones used in the pre-specified scenarios, which rarely sail between just 2 ports. Allowing the user to specify the distances for laden leg and ballast leg of the voyage separately will provide an easier way for the user to calculate the emissions for the entire voyage in this kind of trade. This is one of the main differences that have been made in the *Marine Emissions Evaluator*.

5.2.2 *The Marine Emissions Evaluator*

The emissions calculator created for this study is a Microsoft Excel-based, whereas, the calculator by the NTUA is a web-based. The *Marine Emissions Evaluator* is meant to work as an aid to assess the exhaust gas emissions from ships and keep track of those emissions over time. The *Marine Emissions Evaluator* is divided into three Excel sheets. The first sheet, named ‘Calculator’, collects data which is used in emissions calculations and then it calculates the emissions. To the second sheet, ‘Cumulative Results View’ the user may save the emission data from all the voyages and it will keep track of those and calculate the cumulative emissions from the saving period. The third sheet is called ‘CO_2 Financial Impact Evaluator’. This page allows the user to set a price for the EUA’s and thus calculate the financial impact of CO_2 emissions for different possible scenarios.

In this part of the thesis the *Marine Emissions Evaluator* is introduced in greater detail. All three of the different Excel sheets are now reviewed separately, starting with sheet one, the Calculator.

5.2.2.1 *Sheet one – Calculator*

As mentioned above, the first sheet of the calculator is dedicated to the data collection that is used in the emissions calculations as well as calculating the actual emissions. The Figure 10 depicts the entire first sheet of the calculator. From it you can see the separate boxes that divide the calculator-sheet roughly into four sections. The two boxes at the top are the only ones the user can insert information into. The boxes below the first two detail the results of the calculations and the user cannot add anything into them. At the bottom of the calculator you can see a ‘Save Voyage’ button that saves the results of the emissions calculations to the second sheet ‘Cumulative Results View’, which will be introduced after the first sheet.

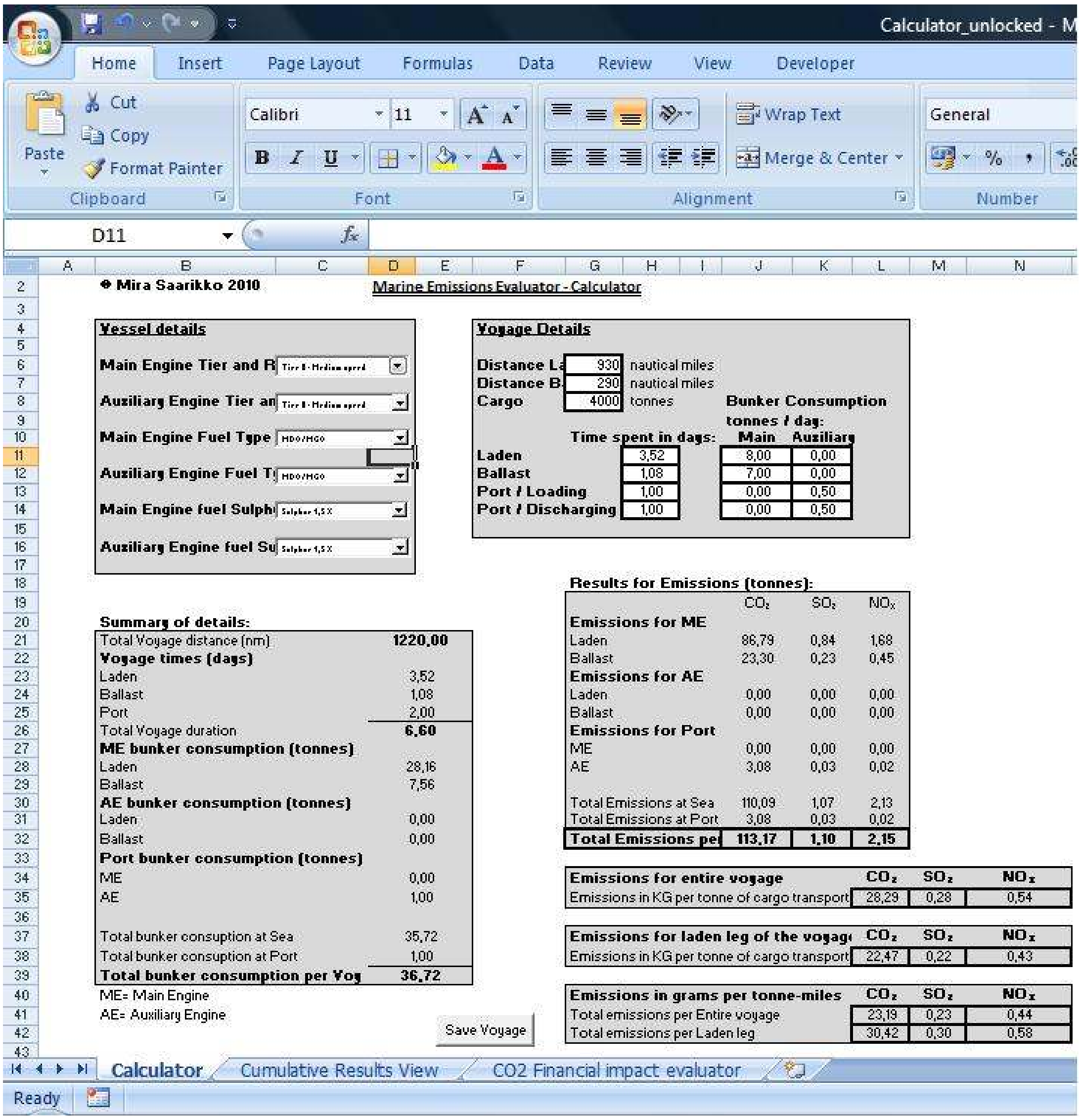

Figure 10 Marine Emissions Evaluator - Calculator

Now that the first sheet of the calculator is introduced in principal, let's look at the individual boxes in detail. The sequence in which the boxes are introduced is from top to bottom and from left to right.

In order to present the calculator as it function in practice, details of an example voyage has been filled in. This voyage is from Pietarsaari to Turku in ballast, from Turku to Rotterdam via Kiel Canal in laden with cargo of 4,000 tonnes.

The first box on the top left is called the 'Vessel details'. In this box the user must fill in the vessel related information that affects the emissions calculation, in ways that were detailed earlier in this chapter. The details that need to be specified related to vessel can be seen from Figure 11.

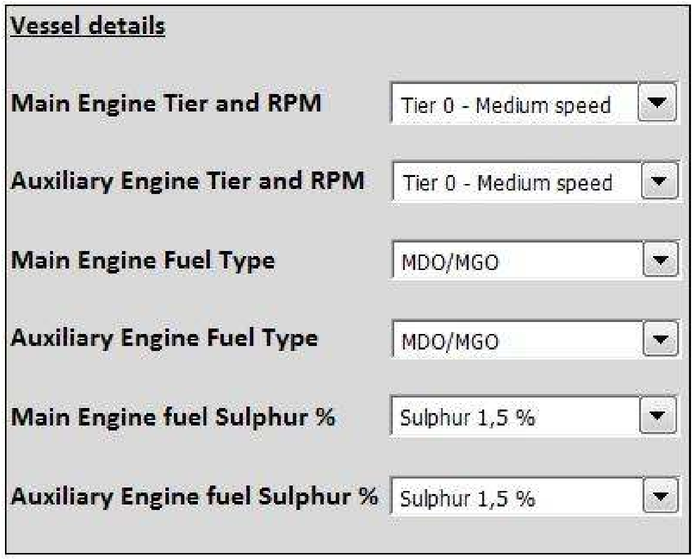

Figure 11 Marine Emissions Evaluator - Vessel details

The vessel details that are needed for the calculation are divided into Main engine and Auxiliary engine information. There are six drop-down menus that give the user the vessel detail options, 3 are for the main engine details and 3 for the auxiliary engine details. The first and second drop-down menu are the engine Tiers 0 and 1, both with slow speed and medium speed option. The third and fourth are fuel type; HFO or MDO/MGO. The fifth and sixth drop-down menus give the option of different sulphur content in the fuel; the choices are sulphur 1.5 %, sulphur 1.0 % and sulphur 0.1%.

If the ship only has one engine or only one engine has been used, then the user must choose the correct points from the main engine drop-down menus and it does not matter what choices are left in the dropdown menus for the auxiliary engine. Once the user has filled in the information into the next box, 'Voyage details' the calculator knows not to take auxiliary engine into account when calculating emissions.

After the vessel details information has been filled in, the voyage details have to be specified. The Figure 12 details the information that is needed of the voyage. Information that is especially crucial for the emissions calculation is the different fuel consumptions, separately for the main engine and auxiliary engine and the duration of the voyage. The duration must be specified for different conditions of the voyage, laden, ballast and port times. Both, fuel consumption and duration are required when calculating the total emissions.

The other information that is filled in the voyage details box are the distances of the voyage, for both the laden and the ballast leg and the amount of cargo carried. This additional information is needed for calculating emissions in relation to the quantity of cargo transported. In order to calculate the emissions for the entire voyage and the laden leg of the voyage, the distances must be separated.

Voyage Details

Distance Laden	930	nautical miles
Distance Ballast	290	nautical miles
Cargo	4000	tonnes

	Time spent in days:	Bunker Consumption tonnes / day: Main	Auxiliary
Laden	3,52	8,00	0,00
Ballast	1,08	7,00	0,00
Port / Loading	1,00	0,00	0,50
Port / Discharging	1,00	0,00	0,50

Figure 12 Marine Emissions Evaluator - Voyage details

Figure 13 summaries all the details of the voyage, such as, the total distance of the voyage, the duration of different stages of the voyage and the total duration and the fuel consumption at different stages of the voyage.

Summary of details:

Total Voyage distance (nm)	**1220,00**
Voyage times (days)	
Laden	3,52
Ballast	1,08
Port	2,00
Total Voyage duration	**6,60**
ME bunker consumption (tonnes)	
Laden	28,16
Ballast	7,56
AE bunker consumption (tonnes)	
Laden	0,00
Ballast	0,00
Port bunker consumption (tonnes)	
ME	0,00
AE	1,00
Total bunker consuption at Sea	35,72
Total bunker consuption at Port	1,00
Total bunker consumption per Voy	**36,72**

ME= Main Engine
AE= Auxiliary Engine

Figure 13 Marine Emissions Evaluator - Summary of details

The last box in the 'Calculator' sheet is the most interesting one. This details the results of the emissions calculation. Figure 14 gives the outline of the results of CO_2, SO_2 and NO_x emissions. The results are specified by engine type, main engine and auxiliary engine, and by emissions at sea and emissions while in port. And of course, the total emissions are calculated.

Below the 'Results for Emissions' box are the emissions per cargo carried. The information about the emissions is given separately for the entire voyage and laden leg plus port times. In order to get this information out of the calculator the user must input the voyage distance information into the 'Voyage details' box earlier. The separation between entire voyage and laden leg plus port times is done in the calculator because; customers of transportation services will most likely want the emission information only for the part that the ship is actually transporting cargo. However, the ship owner must know the total amount of emissions that result from the voyage. The information box below 'the emissions per cargo' boxes is the box that details the emissions per tonne-miles. These are again given separately for the entire voyage and laden leg of the voyage.

Results for Emissions (tonnes):

	CO_2	SO_2	NO_X
Emissions for ME			
Laden	86,79	0,84	1,68
Ballast	23,30	0,23	0,45
Emissions for AE			
Laden	0,00	0,00	0,00
Ballast	0,00	0,00	0,00
Emissions for Port			
ME	0,00	0,00	0,00
AE	3,08	0,03	0,02
Total Emissions at Sea	110,09	1,07	2,13
Total Emissions at Port	3,08	0,03	0,02
Total Emissions per voy	**113,17**	**1,10**	**2,15**

Emissions for entire voyage	**CO_2**	**SO_2**	**NO_X**
Emissions in KG per tonne of cargo transported	28,29	0,28	0,54

Emissions for laden leg of the voyage and port time	**CO_2**	**SO_2**	**NO_X**
Emissions in KG per tonne of cargo transported	22,47	0,22	0,43

Emissions in grams per tonne-miles	**CO_2**	**SO_2**	**NO_X**
Total emissions per Entire voyage	23,19	0,23	0,44
Total emissions per Laden leg	30,42	0,30	0,58

Figure 14 Marine Emissions Evaluator – Results for Emissions

What the user must take notice of, is the different units in which the result information is given in the calculator. For the total emissions in Figure 14 the unit is tonnes, whereas, for the emissions per cargo tonnes the unit is kilograms and lastly for the emissions per tonne-miles the unit is grams. There are differences in unit because using only tonnes as the unit of measurement, would lead to results that are shown with great number of decimals. Changing the unit of measurement makes it easier to understand the amounts of emissions. However, it does require that the user pays attention to this fact.

5.2.2.2 *Sheet two – Cumulative results view*

The second sheet of the emissions calculator acts as a databank of previous voyages for the user. The user is able to save the voyages that he specified in the 'Calculator' sheet. The Figure 15 shows what the entire 'Cumulative Results View' sheet looks like.

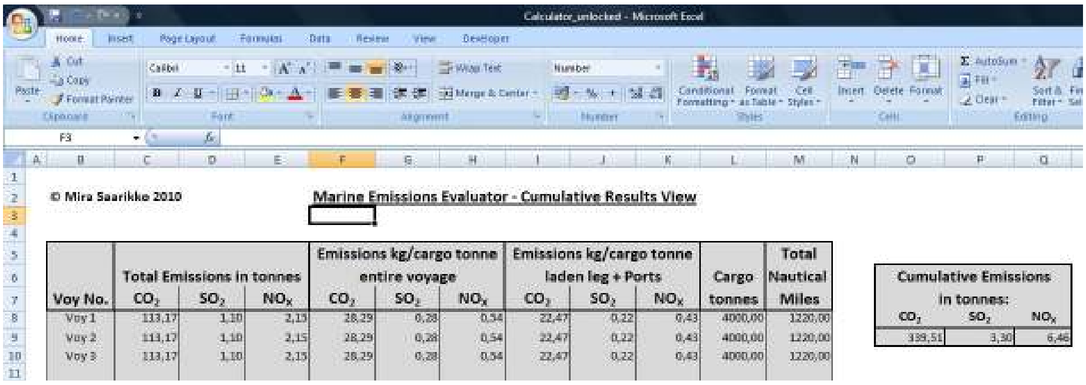

Figure 15 Marine Emissions Evaluator – Cumulative Results View

The different voyage information that is stored in the second sheet can be seen from Figure 16. The programming of the calculator numbers the voyage on a continuous basis starting with 'Voy 1' from the first time the user saves a voyage from the 'Calculator sheet'. The voyages are numbered in order to indentify the different voyages from one another. Next columns are the total emissions for CO_2, SO_2 and NO_x. After which the emissions are presented in relation to cargo quantity. Both 'entire voyage' and 'laden leg and port times' are both presented in the stored data. The last information that is gathered from individual voyages is the cargo quantity and the total distance of the voyage in nautical miles. The cargo quantity is added to the gathered information because there might be a situation in which the emissions in relation to cargo quantity vary significantly from one another. In this case the user can easily see if the reason for this is, that some emissions are divided to a larger quantity of cargo than others. Therefore, the emissions per cargo tonne are smaller than in a case where there is a smaller quantity of cargo and the emissions per cargo tonne are, of course, higher.

	Total Emissions in tonnes			Emissions kg/cargo tonne entire voyage			Emissions kg/cargo tonne laden leg + Ports			Cargo	Total Nautical
Voy No.	CO_2	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2	SO_2	NO_x	tonnes	Miles
Voy 1	113,17	1,10	2,15	28,29	0,28	0,54	22,47	0,22	0,43	4000,00	1220,00
Voy 2	113,17	1,10	2,15	28,29	0,28	0,54	22,47	0,22	0,43	4000,00	1220,00
Voy 3	113,17	1,10	2,15	28,29	0,28	0,54	22,47	0,22	0,43	4000,00	1220,00

Figure 16 Marine Emissions Evaluator – Cumulative results

The last information box of the Cumulative Results View, Figure 17, is among the most important information that can be gathered from the *Marine Emissions Evaluator*. This is the cumulative emissions for CO_2, SO_2 and NO_x. This box adds together all of the emissions that are saved from the 'Calculator' sheet to the 'Cumulative Results View' sheet. If the saving period is, for example, a year, the user will easily know all the emissions a ship has emitted during that time.

Cumulative Emissions in tonnes:		
CO_2	SO_2	NO_x
339,51	3,30	6,46

Figure 17 Marine Emissions Evaluator - Cumulative emissions

If the calculator is updated individually for each ship after every voyage, the user can add together the individual ship's cumulative emissions to get the entire fleets' cumulative emissions. If maritime industry is added to the EU ETS system as the EU is suggesting, the CO_2 emission quantity of the entire company becomes vital knowledge for the management. The total emissions for the actual voyage data used in this thesis can be viewed from the 'Cumulative Results View' pages on Appendix 1.

If maritime industry is added into the EU ETS the user can monitor and compare the emissions allowances the company holds against the emissions emitted during a given year and, thus, determine whether the company has excess allowances that it can sell or if it has to purchase additional allowances to cover the emissions that it was emitted.

5.2.2.3 ***Sheet three – CO_2 Financial Impact Evaluator***

The last sheet of the *Marine Emissions Evaluator* is intended for the financial impact evaluation of CO_2 emissions. CO_2 emissions are the only emissions of this thesis that are assessed with the *Marine Emissions Evaluator,* because they are – if maritime industry is included into the EU ETS – the only ones that would be traded in the carbon market. Financial impact assessment of SO_2 and NO_x will be done separate of the *Marine Emissions Evaluator.*

The Figure 18 below depicts the entire 'CO_2 Financial Impact Evaluator' sheet of the *Marine Emissions Evaluator.* The only input the user has to put into the *Marine Emissions Evaluator's* 'CO_2 Financial Impact Evaluator' sheet is the current price of the

European Union EUA allowance price. All of the other information needed for the financial impact evaluation, the *Marine Emissions Evaluator* collects from other sheets.

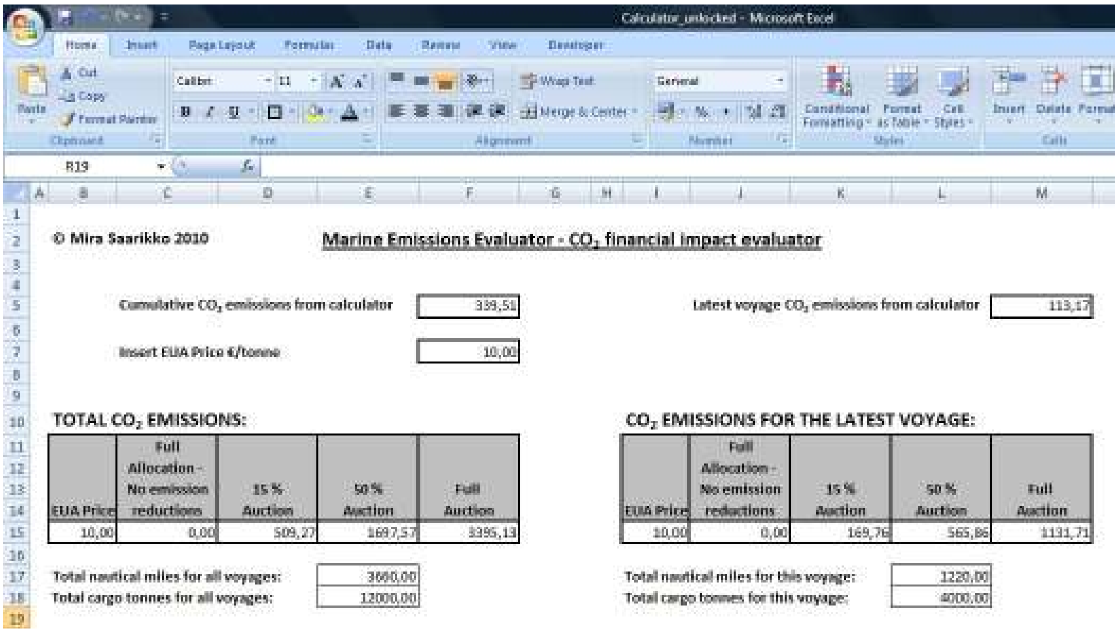

Figure 18 Marine Emissions Evaluator - CO_2 Financial Impact Evaluator

The 'CO_2 Financial Impact Evaluator' sheet has two similar financial impact Tables. First Table on the left illustrates the possible financial impacts of all the voyages saved into the *Marine Emissions Evaluator*. Whereas, the Table on the right only shows the possible financial impact of the most recently added voyage. Figure 19 shows the possible financial impact of the total CO_2 emissions based on three identical trips that was used earlier to illustrate the functioning of the *Marine Emissions Evaluator.* These numbers are only for illustration purposes. A vessel cannot make the example voyage identically three times in a row. The financial impact evaluation sheet of the ship voyage data in this thesis can be viewed in Appendix 2 of this thesis.

Cumulative CO_2 emissions from calculator	339,51
Insert EUA Price €/tonne	10,00

TOTAL CO_2 EMISSIONS:

EUA Price	Full Allocation - No emission reductions	15 % Auction	50 % Auction	Full Auction
10,00	0,00	509,27	1697,57	3395,13

Total nautical miles for all voyages:	3660,00
Total cargo tonnes for all voyages:	12000,00

Figure 19 Marine Emissions Evaluator - Financial impact of total CO_2 emissions

The information that can be seen in Figure 19 is the Cumulative CO_2 emissions from calculator, which will be automatically added to the 'CO_2 Financial Impact Evaluator' sheet from the 'Cumulative Results View' sheet. The user has to then input a price for the EUA allowance and the *Marine Emissions Evaluator* will then compute possible financial impacts for 4 different scenarios. These scenarios range from full allocation of emissions allowance to full auctioning of emissions allowances. The possible financial impact scenarios will be further introduced in the next chapter where financial impact evaluation is made.

The *Marine Emissions Evaluator* also collects the total nautical miles and total cargo tonnes for the user's information. It is useful to know the distance sailed and cargo quantity that has been carried so that the CO_2 emissions possible financial impacts can be put to some context.

Figure 20 is the second Table on the 'CO_2 Financial Impact Evaluator' sheet. It is almost identical to the one illustrated before. The only difference is that this Table illustrates the possible financial impact of the most recently added voyage. It is very possible that cargo owners will be interested in the CO_2 emissions financial impact of their transportation needs and, thus, assessing the financial impacts based on single voyages as well, can be beneficial to the ship owner.

Latest voyage CO_2 emissions from calculator	113,17

CO_2 EMISSIONS FOR THE LATEST VOYAGE:

EUA Price	Full Allocation - No emission reductions	15 % Auction	50 % Auction	Full Auction
10,00	0,00	169,76	565,86	1131,71

Total nautical miles for this voyage:	1220,00
Total cargo tonnes for this voyage:	4000,00

Figure 20 Marine Emissions Evaluator - Financial impact of the latest voyage's CO_2 emissions

Below the financial impact evaluation, the *Marine Emissions Evaluator* shows the user the total nautical miles and cargo tonnes of the most recent voyage to the user, as it did for the total nautical miles and cargo tonnes above.

6 ESTIMATING THE FINANCIAL IMPACT OF EMISSIONS

In this chapter I attempt to assess the financial implications emissions may have for shipowners. Each emission type is discussed individually. The detailed emission quantities for each voyage upon which these assessments are based on can be viewed from appendix 1. This emission data is gathered from actual ship with actual voyages over a period of one year. The sample vessel made 52 trips during the assessment period. The vessel used for data is a dry bulk / general cargo ship with deadweight cargo capacity (DWCC) of 3,950 tonnes and its' main trading area is the Baltic Sea and the North Sea. The ship was built prior to 2000 and, thus it has a TIER 0 medium speed main engine and no auxiliary engine. During the time of the sample data it used MDO/MGO fuel with sulphur content of 1.5 %.

Table 8 Total emission quantities in tonnes for sample vessel in a year

Ship	CO_2 emissions per annum in tonnes	SO_2 emissions per annum in tonnes	NO_x emissions per annum in tonnes
Ship 1	3,724.25	36.25	72.02

Table 8 illustrates the cumulative CO_2, SO_2 and NO_x emissions in tonnes for those 52 voyages the sample vessel made in the assessment period. These figures are used as the basis for the financial impact evaluation.

6.1 Estimating financial impact of CO_2 emissions

The EU ETS works as the guideline according to which the CO_2 emissions are assessed in this study. Four different scenarios were created in order to evaluate different possible financial implications. First scenario is the 'Full allocation based on current emissions'. The second and third scenarios are called '15 per cent auction' and '50 per cent auction'. The final and fourth scenario is 'Full auction'.

6.1.1 *Full allocation based on current emissions or historical emissions*

Full allocation based on current emissions is similar to the ongoing situation in maritime industry. The financial impact for shipowners would be neutralized if the European Union includes maritime industry into EU ETS without any requirements for emissions reductions and with full emissions allowance allocations. However, this scenario is highly unlikely since it would defeat the purpose – actual emissions reductions – of the whole system.

Nevertheless, if low cost emission reductions can be obtained, this scenario may even preset earnings opportunities for shipowners. In this scenario the EU allocates shipowners enough emission allowances to cover all of their current emissions – and without significant increase in those emissions – some emission reductions can be obtained, for example, with more efficient route planning and the lowered fuel consumption consequent upon better route planning. These additional emissions allowances can then be sold in the carbon market to earn money.

The EU might add maritime industry into the EU ETS in a similar way as it does with aviation industry, first a monitoring period to assess total emissions and then reduction in the allocated allowances based on the historical emissions. This would still be considered full allocation, but the base level would just be lower than the actual emissions, in order to reduce the overall emissions of the industry. At the beginning of the aviation industry inclusion, the historical emissions are reduced by 3 %, and the rest are allocated to airlines.

For illustration purposes, assumption is made that maritime industry is included into EU ETS in similar way to aviation industry and the 3 % reduction is accurate to all ships in operation. Reviewing this in the light of the sample vessel emissions data would lead to emissions allowances being 3,612.52 tonnes (original emissions of 3,724.25 * 0.97 %). The difference of 111.73 tonnes of CO_2 emissions would be left. The shipowner would then have to make a decision whether to reduce emissions by that amount or more or purchasing additional emissions allowances. Should the shipowner choose to reduce exactly 111.73 tonnes, he would not have to pay anything extra, nor would he earn anything from excess emissions allowances. The added cost of purchasing those necessary allowances – that is 112 allowances needed to cover the total emissions – is directly related to the price of EUAs at the time of purchase. Table 9 illustrates the possible financial impacts of this situation.

Table 9 Financial impacts of 112 emissions allowances at different European Union Allowance (EUA) prices

EUA Price	5 €	10 €	15 €	20 €	25 €	30 €
Financial impact of 112 allowances	560 €	1,120 €	1,680 €	2,240 €	2,800 €	3,360 €

As can be seen for Table 9, the financial implications of this scenario are not significant. The additional cost of purchasing 112 allowances at different prices can be compared to one additional port call in a year. Depending where that port is situated and its' cost, the CO_2 emissions can easily amount to a significantly lower sum. However, when a shipowner has many vessels these small sums can quickly add up to larger additional cost per year.

6.1.2 *15 per cent auction*

The second scenario is the '15 per cent auction'. In this case the EU allocates 85 % of the emissions allowances free of charge and 15 % has to be purchased by the emitter. 15 % auctioning was chosen, because the aviation industry will have to purchase 15 % of their emissions allowances from very early on after the aviation industry inclusion.

As above, the emissions allowances quantity is assumed to be reduced by 3 % from the actual emissions of 3,724 tonnes during the sample period to 3,613 tonnes. For evaluation purposes the EU would in this scenario allocate 85 % of 3,613, which is 3,071 allowances and the shipowner would have to purchase the rest. The rest are 542 allowances to cover for the reduced amount plus the additional 112 allowances to cover the total emissions of 3,724 tonnes. This leads to purchase of 654 emissions allowances in total. Table 10 illustrates the financial impacts of this scenario.

Table 10 Financial impacts of 15 % auction of emissions allowances at different European Union Allowance (EUA) prices

EUA Price	5 €	10 €	15 €	20 €	25 €	30 €
Financial impact of 15 % auction	3,270 €	6,540 €	9,810 €	13,080 €	16,350 €	19,620 €

This scenario predicts much higher additional costs for shipowners than the previous one. If EU adds maritime industry into EU ETS this could easily be reality before 2015. The aviation industry will have to purchase 15 % of their emissions allowances starting from 2013. If maritime industry is added at the beginning of third trading period on 2013, they will most likely be required to purchase at least part of their emissions allowance starting from the beginning as EU begins the move towards full auctioning of emissions allowances.

If EUA prices remain at a level around 10 € to 15 € per EUA, this additional cost is not yet alarming. It may cause reductions in profits, especially when freight prices are on the lower side. However, when the shipowner has, for example, 10 vessels that are similar to the sample vessel, we could easily be talking about extra annual expenses of 65,000 to 100,000 €. And if the EUA price increases significantly, so do the additional expenses.

6.1.3 *50 per cent auction*

As the EU ETS system is moving towards full auctioning, the 50 % auctioning of emissions allowances would most likely be reached before 2020. When reviewing this scenario with same principle of historical emissions as the 15 % auctioning was done, the additional expenses that could occur can be seen from Table 11.

Table 11 Financial impacts of 50 % auction of emissions allowances at different European Union Allowance (EUA) prices

EUA Price	5 €	10 €	15 €	20 €	25 €	30 €
Financial impact of 50 % auction	9,595 €	19,190 €	28,785 €	38,380 €	47,975 €	57,570 €

In this case the shipowner would have to purchase 1807 emissions allowances to cover for the reduction from historical emissions and the additional 112 emissions to cover the total emissions. At a 50 % auction we begin to see very high annual expenses per ship. Adding this up, for example, for 10 similar vessels and even with a modest EUA price of 10 to 15 €, the additional cost annually would be from 200,000 to almost 300,000 €. This is a sum that would have a noticeable difference in profits.

6.1.4 *Full auction*

The last scenario is full auctioning of emissions allowances. The EU has stated that it intends on reaching full auctioning of emissions allowances by 2027. Full auctioning of emissions allowances for the sample ship data of 3,724 tonnes of CO_2 emissions has the financial impact that is illustrated below in Table 12.

Table 12 Financial impacts of full auctioning of emissions allowances at different European Union Allowance (EUA) prices

EUA Price	5 €	10 €	15 €	20 €	25 €	30 €
Financial impact of full auctioning	18,620 €	37,240 €	55,860 €	74,480 €	93,100 €	111,720 €

This scenario presents very high additional financial costs for shipowners. However, the timeframe in which this stage in EU ETS is reached is so far in the future that many things may have changed before that and predictions are impossible to make.

6.1.5 *Summary of CO_2 financial impact results*

The financial impacts of CO_2 emissions trading vary with very large margin. Table 13 summarizes the results presented above. These results are applicable to a vessel with similar characteristics to the sample data vessel. The first two scenarios should be paid attention to. The last two are more for information purposes as their possible occurrence is further in the future and making predictions is impossible.

Table 13 Summary of CO_2 financial impacts at different European Union Allowance (EUA) prices for the different scenarios

EUA Price in €/tonne	Full Allocation	15 % auction	50 % auction	Full auction
5 €	560 €	3,270 €	9,595 €	18,620 €
10 €	1,120 €	6,540 €	19,190 €	37,240 €
15 €	1,680 €	9,810 €	28,785 €	55,860 €
20 €	2,240 €	13,080 €	38,380 €	74,480 €
25 €	2,800 €	16,350 €	47,975 €	93,100 €
30 €	3,360 €	19,620 €	57,570 €	111,720 €

Lloyd’s ship register contains almost 6,000 small dry bulk and general cargo vessels between 1,000 to 10,000 deadweight tonnes that are built from 1985 to 2010. Sorting out vessels that are not ice capable and have a flag state outside European countries and known flag states leaves us almost 1,800 vessels. Assuming that half of those are in active trading in the North Sea and the Baltic Sea gives us around 900 vessels.

Should all of these be subject to the emissions trading the annual costs for shipowners would be very large. The sample vessel used in this study is roughly from middle of the size scale, assuming that the fuel consumption, and thus emissions, from different size vessels are averaged to somewhere close to the sample vessel, the annual costs of emissions trading with scenario 2 – 15 % auction – and with EUA price of 15 € per allowance, would be around 10 million Euros. This is of course if no emissions reductions are made within the maritime industry.

6.2 Estimating financial impact of SO_2 emissions

As SO_2 emissions are not part of the EU ETS system, it is futile to try to assess their financial impact with the tools designed for financial impact estimation of emissions trading. However, the regulation concerning SO_2 emissions will in all likelihood have a financial effect for the shipowners.

The best way to assess the SO_2 emissions' impact is the increasing fuel cost that results from the stricter sulphur regulations. Whether fuel with lower levels of sulphur is readily available in the years to come remains to be seen. The laws of supply and demand dictate in this situation nevertheless, if the strict sulphur content regulations for SECA do come to pass in 2015, there is certainly demand for the fuel. If supply cannot sufficiently meet this demand, the price of fuel will increase even further.

The sample vessel used around 1,208 tonnes of MDO during the assessment year. As fuel prices respond quickly to the state of the world economy and, thus, vary significantly, it is difficult to set a price for fuel. However, this has to be done in order to evaluate the financial impacts of price increase. For this purpose a price of 600 $ / tonne is chosen. With Euro/US Dollar exchange rate of 1.3, this would be around 460 Euros. With fuel consumption of 1,208 tonnes this would mean fuel purchase costs of roughly 555,000 Euros per annum. Assuming the price will increase due to lack of low sulphur fuel in the future, the fuel costs for the shipowners will increase as well. Table 14 illustrates fuel costs for 1,208 tonnes of fuel at different percentage fuel price increases and the extra costs resulting from fuel purchases compared to base costs of 555,000 €. The fuel base price is set at 460 € / tonne.

Table 14 Fuel purchase costs at different price levels compared to base price and extra costs resulting from increased price

Fuel price increase	25 %	50 %	75 %	100 %	150 %
Total fuel costs	694,600 €	833,520 €	972,440 €	1,111,360 €	1,389,200 €
Extra fuel costs	139,600 €	278,520 €	417,440 €	556,360 €	834,200 €

Fuel price increase leads to additional costs that are greater than the costs resulting from emissions trading. And again these additional costs are presented for single ship only. Assuming, as did above, that the shipowner has 10 vessels and they consume roughly the same amount of fuel as the sample vessel did, the additional costs annually range from roughly 1,400,000 to 8,340,000 Euros depending on percentage of the price increase of fuel.

6.3 Estimating financial impact of NO_x emissions

Estimating the financial impact of NO_x emissions is the most difficult of the three emissions types considered in this thesis. CO_2 emissions' financial impact can easily be assessed based on emissions trading and SO_2 emissions according to increased fuel price. NO_x emissions cannot be assessed by either means. Further the current NO_x regulation affects engines built now and in the future. Some ships are, however, expected to conform with TIER I regulation even though they are installed in a ship prior to 2000. These ships have an engine power output that is greater than 5,000 kW. This does not apply to our sample vessel, which has engine power output of 2,147 kW. This leads to a situation where the current NO_x regulation does not generate any additional financial impacts for the shipowner when they are operating vessels similar to the sample vessel. Current regulation will probably affect the price of engines in the future, especially if the strict TIER III NO_x limits come to pass. As the feasibility study for this has yet to be completed, it is futile to try to guess what their price would be in the future. Thus, no extra financial burdens are assumed to be generated from NO_x emissions in this study.

The fact, however, is that NO_x emissions from shipping are growing in Europe and the current regulation is unable to limit the growth as vessels have a lifespan of 25 to 30 years. Older, and more NO_x will still be in active trade in 2020 and beyond if no other regulations are adopted. In response to this there are different studies suggesting voluntary emissions trading for NO_x emissions. Technical means of significantly reducing the NO_x have also been developed.

These studies dedicated to evaluating different market based tools for NO_x emissions reductions are, for example, Harrison et al. 2005 NERA Report and the Swedish Shipowners' Association report of 2006 both of which introduce market based instruments for reducing NO_x emissions. As these reports are suggestions, their input is not used as tool in this thesis to assess financial implications of NO_x emissions.

There are also technological developments, such as, treating the exhaust gas with *Selective Catalytic Reduction* (SCR) and modifying the combustion process etc. that can be used to reduce the NO_x emissions. However, these tools are too technical for this thesis and their costs greatly depend on the ship, thus, analyzing their financial implication is omitted in this study.

7 CONCLUSIONS

7.1 Summary of the study

Climate change and emissions are a hot topic all over the world nowadays. In a light of this, international shipping has also been subjected to scrutiny. There is much debate over how real reductions in emissions are going to be achieved. With so many conflicting interests of the different parties involved in creating emissions regulations, it is very hard to formulate regulations that would please everybody and yet, at the same time be effective in its designed purpose, reducing emissions from shipping. Because of the current state of mind concerning emissions and climate change, the subject of this thesis is very relevant and important, especially for shipowners. Knowing the current regulations is a must and information about possible changes in regulations can provide competitive advantage.

During this research, my aim was to answer the following research questions:

Q1: How are the ship's emissions quantified mathematically?
Q2: What are the ship's annual emissions?
Q3: What are the possible financial impacts of the ship's annual emissions?

The first and second research questions were supporting questions so that it was possible to answer the final and most important research question. As an answer to the second research question, the *Marine Emissions Evaluator* was created. This tool could easily be adopted by shipowners who are interested in their ships' annual emissions. The final research question could only be answered once the current regulations and possible changes in regulations were reviewed. Thus, the EU ETS and IMO regulations paid a large role in the thesis.

The European Union is leading the way in the global fight against climate change. The EU ETS is the largest emissions trading system to date. It has grown from its beginning as new industries are set to be introduced into the system. Aviation industry's inclusion is set in stone and maritime industry might well be next. If IMO does not come up with a solution that satisfies the EU by the end of 2011, the EU will most likely add maritime industry into the EU ETS as it has stated. This inclusion would most likely be done at a very quick pace, possible inclusion at the beginning of third trading phase in 2013. Considering IMO's progress so far, it is highly unlike that they will come up with a solution, especially since they adhere to the "no more favorable treatment" principle.

IMO has been successful in creating emissions regulations for SO_2 and NO_x emissions, but regulations for CO_2 is still lacking. However, regulations concerning SO_2 and NO_x emissions have met with opposition, especially from Finland and Sweden, due to their strictness and the possible financial burden they may cause. Finland, which is almost entirely dependent on maritime industry, feels that the strict sulphur regulations will have negative effect on trade and they will distort competition in Europe and worldwide as well.

There is a relative consensus among researches concerning modeling of ship emissions. This modeling is often done based on fuel consumption while using emission specific emissions factors. For this thesis this approach was also adopted. With mathematical emissions modeling, emissions for a sample ship were calculated. Based on those real and actual emissions caused by shipping activities during a period of one year, financial impacts were estimated.

7.2 Contemplation of the results of financial impacts estimation

Several different scenarios of financial impacts were assessed. Based on the findings of this research, the ranges of most probable financial impacts for a small vessel are presented in Table 15. Scenario 2, 'the 15 % auction' is chosen as the most relevant scenario. This could be reality already within 5 years if EU adds maritime industry into EU ETS in 2013. In this case the EUA price is assumed to stay within 10 to 20 Euros and the fuel price increase to be between 25 to 100 percent. The other scenarios for CO_2 emissions trading good for information purposes, but most attention should be paid to scenario, where only a small portion of emissions allowances had to be purchased, as this is most likely the situation which shipowners will have to deal with.

Table 15 Summary of most probable annual financial impacts for small 4,000 dwt dry bulk/general cargo vessel

	Range of financial impact
CO_2	6,600 – 13,000 €
SO_2	140,000 – 550,000 €
NO_x	No financial impact

It is clear from Table 15 that the SO_2 emissions regulation has far more pronounced financial impacts for shipowners than CO_2 emissions, not to mention NO_x emissions. However, neither of these impacts are a 100 % certain. Finland, for example, has protested the SECA sulphur regulation for 2015, and it is not yet certain that they are going to be adopted in their current form. If they are, the consequences could be severe, not only for shipping industry, but other industries that depend on international transportation. The additional costs would, nevertheless, be borne by customers of maritime transportation. This would increase the pressure to increase the freight levels in order to cover extra costs due to higher fuel costs and the CO_2 emissions trading. This would significantly affect those industries and companies that require long transport distances for either their finished products, raw materials or both. For companies situated in northern Europe, severe ice conditions and the relating higher fuel consumption could have similar effects.

7.3 Further studies

This subject leads to several interesting possibilities of further study. One of the most interesting and without a doubt important one is, study on how the inclusion of maritime industry into to the EU ETS system will affect the overall competitiveness of European companies heavily dependent on maritime transportation. These companies are, in the end, the ones that will bear the financial consequences of this scenario. They are not able to directly add this extra expense to their selling prices if producers elsewhere are able to provide cheaper alternatives. This leads to heavy pressure on lower production costs elsewhere, which is not an easy feat in a continent where labor costs are significantly higher than in other places.

The regulation according to which maritime industry could be added to EU ETS deserves special attention. Even though aviation industry is already included into EU ETS, the principles according to which it operates are entirely different to those of maritime industry. Those should be carefully considered in order to avoid loopholes in the regulation.

The sulphur regulation also imposes interesting possibilities for further study. First of all is the availability of low sulphur content fuel in 2015. Are the refineries able to produce this and at what price. Additionally, how strong pressure for increase in freight prices, the fuel price increase will create, is a subject worthy of a study. The sulphur regulation mainly affects countries around the Baltic Sea, what will it do to their competitiveness.

These and several more are possibilities of further study. This subject is studied extensively, but there is still room for further studies without them starting to repeat each other.

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APPENDIX 1 THE MARINE EMISSIONS EVALUATOR – CUMULATIVE RESULTS VIEW FOR THE SAMPLE DATA

Voy No.	Total Emissions in tonnes			Emissions kg/cargo tonne entire voyage			Emissions kg/cargo tonne laden leg + Ports			Cargo tonnes	Total Nautical Miles
	CO_2	SO_2	NO_X	CO_2	SO_2	NO_X	CO_2	SO_2	NO_X		
Voy 1	51,46	0,50	1,00	14,70	0,14	0,28	12,84	0,12	0,25	3500,00	800,00
Voy 2	79,12	0,77	1,53	21,98	0,21	0,42	21,21	0,21	0,41	3600,00	1060,00
Voy 3	72,56	0,71	1,40	20,73	0,20	0,40	13,17	0,13	0,25	3500,00	1090,00
Voy 4	14,42	0,14	0,28	3,64	0,04	0,07	1,18	0,01	0,02	3958,00	166,00
Voy 5	54,24	0,53	1,05	19,75	0,19	0,38	15,77	0,15	0,31	2746,00	657,00
Voy 6	28,39	0,28	0,55	9,44	0,09	0,18	8,29	0,08	0,16	3007,00	305,00
Voy 7	54,83	0,53	1,06	13,88	0,14	0,27	13,88	0,14	0,27	3950,00	722,00
Voy 8	52,98	0,52	1,02	15,14	0,15	0,29	12,41	0,12	0,24	3500,00	811,00
Voy 9	76,21	0,74	1,47	21,17	0,21	0,41	20,50	0,20	0,40	3600,00	1060,00
Voy 10	83,52	0,81	1,62	22,88	0,22	0,44	6,04	0,06	0,12	3650,00	1003,00
Voy 11	49,27	0,48	0,95	14,08	0,14	0,27	8,51	0,08	0,16	3500,00	656,00
Voy 12	78,15	0,76	1,51	28,42	0,28	0,55	28,42	0,28	0,55	2750,00	844,00
Voy 13	70,75	0,69	1,37	23,58	0,23	0,46	8,40	0,08	0,16	3000,00	877,00
Voy 14	35,02	0,34	0,68	8,87	0,09	0,17	7,23	0,07	0,14	3950,00	369,00
Voy 15	60,80	0,59	1,18	15,35	0,15	0,30	10,46	0,10	0,20	3960,00	902,00
Voy 16	55,61	0,54	1,08	14,08	0,14	0,27	11,49	0,11	0,22	3950,00	783,00
Voy 17	23,49	0,23	0,45	5,95	0,06	0,12	5,95	0,06	0,12	3950,00	304,00
Voy 18	21,51	0,21	0,42	6,63	0,06	0,13	6,63	0,06	0,13	3243,00	297,00
Voy 19	23,96	0,23	0,46	6,85	0,07	0,13	3,21	0,03	0,06	3500,00	280,00
Voy 20	58,12	0,57	1,12	20,86	0,20	0,40	10,82	0,11	0,21	2786,00	750,00
Voy 21	135,28	1,32	2,62	54,11	0,53	1,05	52,16	0,51	1,01	2500,00	1514,00
Voy 22	218,35	2,13	4,22	87,34	0,85	1,69	75,03	0,73	1,45	2500,00	2109,00
Voy 23	50,01	0,49	0,97	15,15	0,15	0,29	5,44	0,05	0,11	3300,00	579,00
Voy 24	71,57	0,70	1,38	18,84	0,18	0,36	17,54	0,17	0,34	3800,00	1006,00

Voy No.	Total Emissions in tonnes			Emissions kg/cargo tonne entire voyage			Emissions kg/cargo tonne laden leg + Ports			Cargo tonnes	Total Nautical Miles
	CO_2	SO_2	NO_X	CO_2	SO_2	NO_X	CO_2	SO_2	NO_X		
Voy 25	54,15	0,53	1,05	16,41	0,16	0,32	6,15	0,06	0,12	3300,00	724,00
Voy 26	43,36	0,42	0,84	12,39	0,12	0,24	7,91	0,08	0,15	3500,00	648,00
Voy 27	86,32	0,84	1,67	24,32	0,24	0,47	23,61	0,23	0,46	3550,00	1090,00
Voy 28	78,89	0,77	1,53	28,17	0,27	0,54	13,08	0,13	0,25	2800,00	1035,00
Voy 29	58,84	0,57	1,14	16,52	0,16	0,32	14,85	0,14	0,29	3561,00	716,00
Voy 30	67,59	0,66	1,31	23,31	0,23	0,45	14,90	0,15	0,29	2900,00	781,00
Voy 31	68,38	0,67	1,32	20,72	0,20	0,40	9,77	0,10	0,19	3300,00	883,00
Voy 32	66,53	0,65	1,29	16,63	0,16	0,32	15,53	0,15	0,30	4000,00	787,00
Voy 33	115,37	1,12	2,23	32,32	0,31	0,62	19,63	0,19	0,38	3570,00	1759,00
Voy 34	98,86	0,96	1,91	25,03	0,24	0,48	16,03	0,16	0,31	3950,00	1443,00
Voy 35	62,25	0,61	1,20	17,78	0,17	0,34	15,84	0,15	0,31	3500,00	879,00
Voy 36	74,43	0,72	1,44	22,56	0,22	0,44	16,62	0,16	0,32	3299,00	818,00
Voy 37	105,21	1,02	2,03	42,08	0,41	0,81	38,93	0,38	0,75	2500,00	1477,00
Voy 38	119,20	1,16	2,31	36,12	0,35	0,70	8,45	0,08	0,16	3300,00	1483,00
Voy 39	44,91	0,44	0,87	11,66	0,11	0,23	11,66	0,11	0,23	3850,00	802,00
Voy 40	45,50	0,44	0,88	13,79	0,13	0,27	4,93	0,05	0,10	3300,00	804,00
Voy 41	47,87	0,47	0,93	12,43	0,12	0,24	11,57	0,11	0,22	3850,00	787,00
Voy 42	73,46	0,72	1,42	24,49	0,24	0,47	19,09	0,19	0,37	3000,00	1198,00
Voy 43	38,82	0,38	0,75	12,94	0,13	0,25	12,94	0,13	0,25	3000,00	747,00
Voy 44	43,47	0,42	0,84	17,39	0,17	0,34	16,27	0,16	0,31	2500,00	854,00
Voy 45	89,55	0,87	1,73	35,82	0,35	0,69	30,53	0,30	0,59	2500,00	1659,00
Voy 46	112,30	1,09	2,17	32,09	0,31	0,62	28,70	0,28	0,56	3500,00	1978,00
Voy 47	48,84	0,48	0,94	17,76	0,17	0,34	15,80	0,15	0,31	2750,00	810,00
Voy 48	80,13	0,78	1,55	33,39	0,33	0,65	25,88	0,25	0,50	2400,00	1074,00
Voy 49	159,11	1,55	3,08	62,10	0,60	1,20	36,34	0,35	0,70	2562,00	2032,00
Voy 50	100,51	0,98	1,94	40,20	0,39	0,78	20,35	0,20	0,39	2500,00	1394,00
Voy 51	112,84	1,10	2,18	56,42	0,55	1,09	40,45	0,39	0,78	2000,00	1757,00
Voy 52	108,00	1,05	2,09	54,00	0,53	1,04	51,93	0,51	1,00	2000,00	1126,00

Cumulative Emissions in tonnes:		
CO_2	SO_2	NO_X
3724,25	36,25	72,02

APPENDIX 2 THE MARINE EMISSIONS EVALUATOR – CO_2 FINANCIAL IMPACT EVALUATOR

Marine Emissions Evaluator - CO_2 financial impact evaluator

Cumulative CO_2 emissions from calculator	3724,25
Insert EUA Price €/tonne	13,00
Latest voyage CO_2 emissions from calculator	108,00

TOTAL CO_2 EMISSIONS:

EUA Price	Full Allocation - No emission reductions	15 % Auction	50 % Auction	Full Auction
13,00	0,00	7262,29	24207,63	48415,27

Total nautical miles for all voyages:	50489,00
Total cargo tonnes for all voyages:	168442,00

CO_2 EMISSIONS FOR THE LATEST VOYAGE:

EUA Price	Full Allocation - No emission reductions	15 % Auction	50 % Auction	Full Auction
13,00	0,00	210,60	701,99	1403,97

Total nautical miles for this voyage:	1126,00
Total cargo tonnes for this voyage:	2000,00