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A techno-economic comparison between Eco-design and Eco-converted ships

by

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It has been a great learning experience for me.

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Abstract

The aim of the thesis statement is to enlighten the technical and economic aspects of Eco-design and Eco-converted ships. The thesis starts with a well-rounded review of green shipping and sustainability while emission's issue is a significant part of it. Following, the next part is devoted to regulations and methods towards eco-technology. At first, the Energy Efficiency Design Index (EEDI) is mentioned from technical and regulation point of view. Ballast water management is lengthy analyzed, while Energy Saving Devices are extensively examined. At that point, it was author's decision to mention the LNG issue, which is of high significance for the shipping industry. Moreover, in order to get a balanced view, the study presents some Eco-design and Eco-converted ships. Furthermore, the study continues with the economic analysis, which presents the total cost differences between the existing and eco-design ships and the cost benefit analysis, which presents from the ship-owner's point of view the economic differences between eco and eco-converted bulk carriers. Last but not least, there are written some conclusions of the thesis along with the recommendations for further research.

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List Of Abbreviations		
1	BHP	Brake Horse Power
2	BW	Ballast Water
3	CFD	Computational Fluid Dynamics
4	CO	Carbon Monoxide
5	CO_2	Carbon Dioxide
6	CPPs	Controllable Pitch Propellers
7	CRP	Contra Rotating Propeller
8	CSR	Common Structural Rules
9	DNV	Det Norske Veritas
10	DSEC	Daewoo Ship Engineering Company
11	ECA	Emission Control Area
12	EEDI	Energy Efficiency Design Index
13	EEOI	Energy Efficiency Operational Indicator
14	EGR	Exhaust Gas Recirculation
15	EMEC	European Marine Energy Centre
16	ESD	Energy Saving Devices
17	EU	European Union
18	FEA	Finite Element Analysis
19	GHG	Greenhouse Gas
20	GSP	Green Shipping Practises
21	HAPs	Hazardous Air Pollutants
22	HFO	Heavy Fuel Oil
23	ESP	Efficiency Horse Power
24	HSS	Higher Strength Steel
25	IACS	International Association of Classification Societies
26	ICS	Institute of Chartered Shipbrokers
27	ILO	International Labour Organization
28	IMO	International Maritime Organization
29	IT	Information Technology
30	JASNAOE	Japan Society of Naval Architects and Ocean Engineers
31	kHz	Kilohertz
32	LNG	Liquefied Natural Gas
33	MARPOL	Marine Pollution
34	MBM	Market based Measures
35	MDO	Marine Diesel Oil

36	MEPC	Marine Environmental Pollution Committee
37	METS	Maritime Emissions Trading Scheme
38	MGO	Marine Gas Oil
39	MW	Megawatt
40	NOx	Nitrogen Oxides
41	PID	Propulsion Improving Devices
42	PM	Particulate Matters
43	PSD	Pre-Swirl Device
44	SEEMP	Ship Energy Efficiency Management Plan
45	SFOC	Specific Fuel Oil Consumption
46	SMGT	Super Marine Gas Turbine
47	SOx	Sulphur Oxides
48	SPEC	Specification
49	TENT-T	Trans-European Transport Networks
50	TEU	Twenty-foot equivalent unit
51	UHC	Unburned Hydrocarbon
52	UNCLOS	United Nations Convention on the Law of the Sea
53	UNFCCC	United Nations Climate Change Conference
54	VOL	Volume
55	WTO	World Trade Organization

Chapter 1 Introduction

Shipping is one of the world's most international industries and is increasingly growing. Often it has been described as the most cost effective and the most energy efficient transport mode. However, it is a fact that market cycles pervade the shipping industry and it's almost impossible to predict them. Ship owners set their strategies depending on the market conditions. Nowadays, the shipping market is at low levels and shipping companies try to minimize their ships daily running costs by setting eco-friendly techniques. But, are simple techniques enough to keep companies alive and sustainable? Moreover, shipping holds 80% of the total world trade and is responsible for a small proportion of total emissions. Today, green shipping is a burning issue since the global impacts of shipping sector and the demand for improved fuel efficiency are in the first place of consideration. Therefore, the aim of this study is to present the Environmental policies towards greener and sustainable shipping, to define the Eco-design and Eco-converted ships and through economic and cost benefit analysis, to figure out the most efficient choice between Eco-design and Eco-converted bulk carriers, from the ship-owner's point of view. The study consists of 4 chapters, namely: Green Shipping and Sustainability, Regulations and actions towards Eco-technology, Eco Ships & Economic analysis.

Green Shipping refers to actions which can be either management practices or new measures that shipping organizations adopt in order to mitigate their contribution to global pollution. Green shipping refers not only to environmental protection but also to resource conservation. Green policies are discussed by major firms and several governmental offices since the issue has been argued by regulatory organizations such as the International Maritime Organization (IMO). More specifically, green policies constitute a wide range of actions, from improving propulsion system and optimizing hull design to taking advantage of renewable sources and adopting LNG as fuel. The currently existing technology is sufficient for improving energy efficiency of ships even up to 30% and for eliminating considerably the environmental impacts. The organizations that establish green shipping strategies achieve balance of economic and environmental performance and at the same time are in line with the institutional requirements. Further, the definition of sustainable shipping that examines the issue of shipping under three pillars shows a path to green shipping. This concept is examined under economical, development, social development and environmental protection. Sustainability also includes a wide range of concepts from technological innovation and international competition to personnel development, in order to meet the requirements which are in line with the elimination of the problems that shipping sector faces. In particular, ship waste treatment, ballast water treatment and emissions are issues which put in danger the eco system. Emissions constitute a crucial issue since their negative impacts on the environment and on the human health are tremendous. IMO has set limitations for the released emissions from shipping and at the same time promotes policies and potential solutions about the control and the mitigation of all types of emissions. All activities of the shipping sector produce emissions and more specifically, Particulate Matters (PM), Nitrogen Oxides (NOx), Sulphur Oxides (SOx), Carbon Monoxide (CO) and Carbon Dioxide (CO2), Green House Gases (GHG) and other dangerous pollutants. By 2050 the CO_2 emissions are predicted to be increased by 126%-218% and the shipping sector is expected to be responsible for 12%-18% of the total CO_2 emissions. Nonetheless, the existing technology is suitable for the existing ships and can significantly reduce all types of emissions. In particular, SOx emissions can be even by 85%-99% mitigated, NOx emissions can be reduced by 90%-95% and effective measures can decrease CO_2 emissions by 25%-75% comparing with current levels.

The chapter of Regulation and Methods for Eco-Technology presents the Energy Efficiency Design Index (EEDI) and the various methods for improving energy efficiency. The index is proposed by IMO in order to control the CO_2 emissions from the shipping sector. According to the IMO estimations, the adoption of the EEDI and the Ship Energy Efficiency Management Plan can lead between 17% and 25% reduction of CO_2 emissions, comparing with the current conditions. Moreover, the actions that are suitable for improving power efficiency are examined under the scope of propulsion efficiency, hull design, main engine improvements and LNG as fuel. Also, alternative technologies focus on renewable energy sources which also contribute to CO_2 mitigation.

The core of the study focuses on the analysis of eco-ships. The eco-ships are cleaner, greener and more efficient vessels. They are major key factors to shipping sustainability and to efficient transportation. Until now, many shipping companies have manufactured eco-ships or converted their vessels to eco-designs by adopting green and innovative technologies. The eco-ships balance the economic and the eco-friendly shipping. They aim to optimize their power efficiency, to improve their negative impacts on the environment and become more profitable for the ship-owners. The study provides examples both for eco design ships and eco-converted.

Thereafter, the upcoming challenges in the shipping sector concerning fuel prices and environmentally regulations can be dealt by the existing options that are in line with green shipping concepts. Not only the environmental issues can be effectively arranged but also ship-owners can become more profitable. This study will contribute to the increase of awareness about green shipping, the various methods that will contribute to the efficiency improvement and to the elimination of the negative footprint on the environment as well as the significant benefits of implementing new technologies to the ships.

Chapter 2 Green shipping & Sustainability

2.1 Introduction

Nowadays the hazardous effects of shipping such as air pollution seem to be in the first place of consideration by major firms and several governmental offices. The issue of green shipping has caught the attention of regulatory authorities and organizations such as the International Maritime Organization (IMO). There are existing regulations set by IMO for the control and for the mitigation of shipping pollution. Moreover, IMO has proposed additional measures as well as green actions and has set limitations for the future in order to prevent pollution from the shipping sector. The strategies that the firms implement focus on improving the environmental performance of shipping activities. The improvements, as concerns decreasing emissions and in general minimizing the negative effects of the shipping sector are introduced by green shipping practices. Many shipping firms have begun to be environmentally concerned by installing ''green'' shipping technology and take actions to make their overall operations more environmental friendly. The ''green'' practices are management practices that shipping organizations adopt to mitigate their contribution to global pollution. In particular, ''green'' policies constitute a wide range of actions, from improving hull efficiency and optimizing hull design to taking advantage of renewable energy sources and installing energy saving devices. The existing technology is sufficient for improving energy efficiency of ships and for eliminating the environmental impacts considerably. The firms that adopt ''green'' shipping policies achieve balance of economic and environmental performance and at the same time are in line with the institutional requirements.

2.2 Green Shipping

Green shipping intends to eliminate the negative environmental impacts of the shipping sector while increasing the knowledge of the stakeholders. After research in future fuel economics (Acciaro. M 2013), it is obvious that the shift to alternative fuels will not only be necessary due to environmental sensitivity but also to the increasingly high fuel prices. More specifically, the average price, dollars per barrel in 2035 will be between 100$ and 120$ as a result of an IMO MBI study. Moreover it seems from the same study that the levels of bio-fuels production had a significant increase, as in 2010 reached the level of 100-120 billion liters. From the research of upon future fuel trends, it is predicted that prices of Heavy Fuel Oil (HFO) will be 500-900$ per ton and the Marine Diesel Oil (MDO), Marine Gas Oil (MGO) prices will reach almost 30-40% above those of the HFO. It is expected that the prices of gas and oil will decrease and that shale gas will possibly increase the spot gas deposits. It is also predicted that the increased demand of alternative fuels such as bio-fuels, distillates and Liquefied Natural Gas (LNG) will be inadequate. Even those days the global LNG price does not exist, the price is predicted to reach the level of 300$ per ton, initially for the predicted period and 650$ per ton up to 2035. LNG prices could be also lower than those of the oil fuel, although the application of LNG for the maritime sector is likely to be inadequate. Even though bio-fuels could be actual an alternative solution, they cannot be fully adopted because of techno-economic factors.

The raise of fuel prices could cause the doubling of the freight rates, fluctuations in global transactions as well as the reduction of ship trading speeds (Acciaro, et al. 2012). As it has been proved, energy efficient ships can be up to 20%-30% (EMEC 2010) less fuel consuming, the application of systems that promote green shipping and sustainability is essential. It is also demonstrated that it should be ensured, that the efforts towards environmental protection would not at the same time negatively influence reliability of green systems (Acciaro, et al. 2012). Consequently, there is the necessity for governments to focus their attention on examining the regulations that cover the world transport system.

Improvements in terms of decreasing pollution and consequently increasing efficiency are introduced by technological innovations in the marine equipment area and by regulations that promote green shipping. Also, if new innovations and developed technologies were introduced, then ships could be 33% more environmentally friendly (EMEC 2010). Marine equipment refers to any product or service that is necessary in the whole chain of the shipping sector.
Until today the term of sustainable shipping lacks of a definition that is widely accepted, although Cabeza-Basurko et al. (2008), p.3 proposed a definition of sustainable shipping (or "sustainable waterborne transport") as it follows:

> *"A cost-effective commercial activity, in which the environmental load is not bigger than that which the environment can currently and in the future bear, and that the social community (directly and indirectly) in contact with it is not being negatively affected".*

Nowadays, sustainable development is examined under three sections which were elaborated at the World Summit on Sustainable Development in Johannesburg 2002. Consequently, sustainable shipping should be researched under the three pillars, namely economic development, social development and environmental protection. In terms of economic development the main concept is to develop economic growth without negatively influence social and environmental development. The economic key area covers sections such as international competition, efficiency and optimization, investments on innovation, technology and infrastructure, external costs of maritime transport and economic instruments in terms of taxes or market-based measures. As the definition quotes, social developments refers to the well-being of people, consequently it covers sections such as personnel educational development, working conditions and rights (e.g. safety, working environment) and social aspects (e.g. passenger rights, health, security). Moreover, the pillar of environmental protection deals with the footprint of shipping on the environment, as a result it covers the sections of pollution and its impacts (e.g. global warming, greenhouse effect) as well as the materials used to the whole supply chain of the shipping sector.

2.2.1 EU actions during 2001-2011

It is interesting to present the historical path in a decade in terms of EU actions towards sustainability. In 2001 Commission published the 2001 White Paper. "Commission

White Papers are documents containing proposals for Community actions in a specific area. In some cases they follow a Green Paper published to launch a consultation process at European level. When a White Paper has been favourably received by the Council, it can become the action programme for the Union in the area concerned. White papers are also often the fore-runners to legislative proposals" (*EPSD: Sustainability in the European Union, 2012).* Initially, the Commission suggested the disconnection of the transport growth with the economic development. The decongestion of road transport modes is encouraged through an action programme; the development of the rest means of transport such as railway or water transport. Although, a fundamental method was introduced, Marco Polo Programme, it supported initiatives and alternative ways to road transportation. In order to diminish road transport, White Paper supported the plan of motorways in the sea transport network, which would have more or less the same operational rules with land motorways. This solution could generate significant levels of efficiency in transportation system and launch development in the area of sea motorway infrastructure.
The mid-term review of the White Paper was published in 2006 by the Commission. Globalisation led to a massive change in the area of transportation, as logistic companies were founded with international profile (*EPSD: Sustainability in the European Union, 2012)*. Although, White Paper had predicted greater economic growth and therefore investments in infrastructure were affected. It was obvious that the transport policy should have a general approach not only at EU point of view because the actions in EU levels did not seem to be sufficient. In the end, in the review it was proposed to develop tools with an approach as a unit in terms of sustainable transportation. Finally some points that were highlighted are safety issues, working conditions, energy consumption and emission impacts.

In 2007, the Commission published the "Keeping Freight Moving 2007", which proposed tools to achieve a sustainable freight transportation system. The policies focused on making simpler the transportation procedures, formulisation of EU security guidelines for shipping and personal training in the area of logistics as well as formalisation of the loading units between the different modes of transport.

In 2008, the Commission published the "Greening Transport", which contained the measures that contribute to the efforts towards sustainable transportation. The proposed measures covered issues such us climate change, pollution (in particular air and noise pollution) and the increased road transportation. Moreover in 2008, new medium-term measures were presented in order to generate sustainable transportation. In particular the plan of internalising external costs which means that the costs of transportation should represent the costs that the transportation as a service would induce to the society. The expected costs in 2020 due to air pollution (e.g. CO_2), made the internalisation of those an urgent issue. In addition, in 2006 NAIADES programme proposed the internalisation of the costs for "inland waterway" transport by 2013.

In 2009, the Commission published the "Sustainable Future for Transport". The efficient transportation had been effectively promoted since almost one third of the investments had been absorbed, as well as pollution and accidents in sea had drastically reduced (*EPSD: Sustainability in the European Union, 2012).* However, environment still seems to suffer from the inadequate efforts to mitigate greenhouse gases and other hazardous emissions. It is important to report that transportation sector at those times had the fastest growth rate as far as it concerns greenhouse gases emissions. In addition, “The Climate and Energy package” [Directive 2009/29/EC] had established a legally binding goal of 10% alternative energy resources of transport by 2020. As it seems the Commission did not promoted new actions, rather it was highlighted the increasingly demand rate for transportation, the further globalisation, the potential lack of fossil fuels and in general the important upcoming changes.

In 2011, another White Paper was published by the Commission. This White Paper introduced mainly the predictions about social and environmental issues. Specifically, it was predicted that the EU CO_2 emissions would be doubled by 2050 and also that oil products would still possess the market of transport energy (89% share of the market). In addition, society would suffer from congestion, causing 50% more costs by 2050. As a consequence, it was obvious that previous policies were not effective at all and did not achieve their goals. The main issues that kept the development back seem to start with the lack of coordination between the Member States in terms of costs internalisation. Unfortunately, the investments were also not enough to cover the problem of congestion as well as the investments of the TEN-T strategy, where TEN-T is a component of the “Trans-European Networks” (TEN).

In order to change the transport system into sustainable, the White Paper 2011, sets 10 goals which should be met by 2050. It also forms a challenging long term plan, as the goals for 2050 even for 2020/30 did not seem to be easily achieved. The mid-term goal, in particular by 2030, is a 20% decrease in transport emissions (compared to 2008 levels). Long term goals referred in reducing the greenhouse emissions by 80% compared to 1990 and by 60% transport emissions compared to 2008. In maritime transport, White Paper set that by 2020, transport dependency from oil products should be diminished in significant levels according to the EU Strategy 2020. Moreover, as the maritime transport is also responsible for CO_2 emissions, a decrease by 40% of those, compared to 2005 levels should be established by 2050. In addition a goal that was set in order to decongest road transport referred to a 30% transfer from road transport (>300 km) to rail or “waterborne transport” by 2030, and over 50% by 2050. Additionally, according to the White Paper, the TEN-T was proposed in order to be applied by 2030 and the operation of the network should have reached high standards in terms of quality and capacity by 2050. Moreover, every port should be effectively connected with railway stations or even “inland waterways”, if possible. Finally, the White Paper suggested the use of information systems such as (ITS, SSN, LRIT, RIS and Galileo) in order to optimize efficiency between the sector of transportation.

2.2.2 Environmental Policies towards Green shipping

The policies proposed referred to a wide range of issues. At first, according to White Papers, it should be examined the establishment of a flag which *“would represent quality and certification of safe, secure, environmentally friendly ships manned by highly qualified professionals”.* More specifically, the Commission highlights the necessity for “clean, safe and silent ships”, as a result alternative fuels, innovation in infrastructure and in information systems are required.

Moreover, a network of “Single European Transport Area” was proposed in White Paper to be established which will contain western and eastern part of the EU and it will be defined with TEN-T guidelines. It is also important to refer that an infrastructure funding has to be planned in order the TEN-T to be completed as well as other infrastructure programmes and at the same time to be examined whether the infrastructure funds contribute to energy efficiency and to the efforts over environmental protection. In the White Paper of 2011 is also mentioned that the establishment of "multimodal freight corridors" should be in the core network and "multimodal transport, inland waterway transport and eco-innovation" should be launched.

It is also important focusing on the International Maritime Organization actions. The Marine Environmental Pollution Committee (MEPC) is a sub-organization of the IMO which promotes actions in favour of seas and air protection. In 1978, IMO modified the International Convention for the Prevention of Pollution from Ships, which is called MARPOL 73/78. This protocol sets the standards for fuel oil, wastewater and garbage generated from ships. Between 2001 and 2011, two aspects seem to be fundamental; the “intermodal transport” and the integration of different national transport networks (Europa, 2012). The basic tool for “intermodality” is the TEN-T which offers a basis for telecommunication, energy and transportation. TEN-T is extremely necessary in the single market of European Union, as it requires the application of free movement of foods, persons and services and as well as the facilitation of transportation networks between the Member States.
Another essential tool for “intermodality'' could be Marco Polo II, which is the extension of the first Marco Polo programme. The aims of this programme were the same as those of Marco Polo I, to decongest the transportation of roads and promote alternative modes of transportation, but in a wider geographical extent. Moreover, other aspects included such as mitigating structural obstacles of the transportation market and the “motorways of the sea”. The relevant acts were the establishment of Marco Polo II programme for improving the environmental performance of the freight transport system.

In addition, IMO has proposed measurement tools such as the Market based Measures (MBM). In particular, IMO (MEPC64 Documentation) proposed an obligated limit in the Efficiency Design Index (EEDI) for new vessels, obligated or voluntary report of EEDI, for Energy Efficiency Operational Indicator (EEOI) as well as obligated or voluntary use of Ship Efficiency Management Plan for the new vessels. EEDI will be extensively analysed in further chapters.

Last but no least, in terms of actions towards green shipping, the sulphur Directive plays an important role. It presents that the goal for 2020 is 0.5% level of sulphur in seas. A future plan seems to be the possibility of EC to contain other ECA’S as part of the “Air Quality Directive”. Another issue is that even if the Hong Kong Convention about recycling has been signed, still there is no validation.

2.2.3 Current problems and possible solutions

The issues that could be further analyzed in terms of current problems and potential solutions are being presented below.
One of the problems is the ship waste which very often ends up in seas. Ship water treatment is regulated by the Directive 2000/59/EC. The definition of garbage is: "*Garbage includes all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of the vessel and liable to be disposed of continuously or periodically."* In some cases, ship-owners choose to discard ship garbage in the sea, resulting in severe environmentally problems, even in the flora of the oceans. It is a fact that 70% of the garbage sinks in the bottom of the sea, 15% reaches the shores and the rest 15% floats on or under the sea surface creating garbage islands. As a result, the accumulated garbage in the sea transfers pathogens disturbing environmentally life in seas. Currently, there are possible solutions in the waste treatment problems. Firstly, ships in order to make the volume of the garbage manageable, should adopt a system of compression. This system allows decreasing the volume of the garbage in significant levels and offering the possibility to discharge the garbage overboard. An alternative choice is "plasma technology", a system that reduces waste, as it converts it using high temperatures into non-toxic sludge. The compounds which form plastic, for example can be transformed into hydrogen and carbon dioxide.

A second serious problem is when sludge (used lube oil and fuel sludge) ends up in seas. When ships use low quality of fuel, more expenses are required in order to improve its quality before it can be used. The process of treatment leaves a mixture of water and oil, the sludge. As the discharge of it is expensive, ship-owners reduce it to minimum through the bilge water treatment. This is a process that separates the water from the sludge and sends it overboard. The problem is that the water disposed in the sea includes oil. This method of discharging water to the sea is called bilge water treatment system. Possible solutions could be firstly, the choice of a better quality fuel as it could contribute not only to the reduction of oil pollution but to the longer engine lifetime. Moreover, there is an existing technology in managing effectively bilge water, in order to avoid the leak of oil into the sea. More specifically, technologies such as high speed centrifuges and cascade tanks could contribute in a significant level. The latter uses gravity in order to lead water to the bottom of a tank and sponges in order to cleanse it. Centrifuges are used in combination with micro filtration in order to separate efficiently water and oil.

Furthermore, an adverse effect in the environment creates the fact that black and grey water reaches the sea. . Black water is a term used to describe wastewater containing faecal matter and urine (water from toilets). Grey water is a term generally used to describe water generated from domestic activities such as dishwashing, laundry and bathing. Water of this kind contains harmful components such as detergents, elements of plastic or kinds of fat. The disposal of this kind of water near to coasts could cause hygienic problems and deteriorate environmental conditions. It is important to mention some systems which are installed in ships and that play a significant role to the purification of the water. Membrane Bioreactors is a sewage treatment system that can effectively cleanse black and grey water. It uses a filter and membrane modules in order to clarify the water before it is disposed to the sea. A second system that could be installed is vacuum toilets. By using grey water to the toilets, its volume is reduced by 75% and by using sludge reactors combined with membrane filtration black water is minimized by 1/3.

Moreover, the composition of the antifouling paints also causes marine pollution. This kind of paints is used to prevent organisms attach and stay on the surface of ships because eventually they are responsible for the corrosion of it. However, some of them have dangerous components that can be harmful to the marine organisms. The solutions that are analyzed, suggest the use of “modern biocide release” systems with short life expectancy, which reduces the biocide emissions in the sea. Also, the adoption of the “biocide-free fouling control paints” system is suggested which is suitable for ships that are under specific operational conditions. (E.g. slow speed). Bio fouling is not covered directly by the “anti-fouling Convention” and the “BWM Convention.” Although, Bio fouling is covered under the ISCG rule on ballast water and in EPA VGP and it seems that IMO will propose a regulation which will cover bio fouling up to the next ten years.

To conclude, it is essential to further research the parts that are connected with the idea of green shipping in a ship’s life-cycle. As far as it concerns the materials used, the European marine equipment manufacturers are researching in terms of further innovation materials that can be used in shipping which have more eco-friendly character. The European equipment manufactures also try to optimize the complicated supply chain in the shipping sector in order to generate the best levels of efficiency. Electronic tools that could help communication seem to be required in order to diminish the impacts on the environment due to inefficiency of the supply chain. Moreover, the concept of automation could play a role. By installing automation in ships, not only safety for the crew is ensured but also accidents that have as result environmentally pollution can be avoided.

2.3 Ships Emissions

Even if the shipping sector is the least environmentally harmful mode of transport, the activities included in influence negatively the environment. The footprint of shipping on the environment has many different aspects and one of those is air pollution. In particular, shipping produces emissions such as Nitrogen Oxides (NOx), Sulphur Oxides (SOx), Carbon Dioxide (CO_2) and Green House Gases (GHG). The air pollution is subsequent of all activities in maritime transport and the development of it is expected to be high in the next years. As a result atmosphere and public health are under threat.

Figure 1, source: marineinsigh.com, June, 2012

For the next years, IMO has set limitations for the released emissions from shipping and at the same time promotes policies and potential solutions about the control and the mitigation of all types of emissions. The new technologies can efficiently contribute to emissions reduction and their potential solutions ranging from technological actions and operational modifications to market-based tools. In addition, calculation of the level of emissions, the geographical identification of the affected by the emissions areas and the implementation of suitable strategies are necessary in order to mitigate the level of emissions, otherwise the long-term results could be catastrophic. The issue of emissions requires the concern not only of the shipping sector but also the public. The collaboration of those parts will result to efficient and long-lasting changes.

The globalization of maritime transport has led to the increasing growth of the sector. Nowadays, maritime transport holds an important share of the global trade. As a result of this sector's growth, areas close to ports and coasts suffer from the vessel's emissions and the problem probably will grow as the maritime transportation sector will be developing. According to IMO Green House Gases Study, shipping sector over time is the least environmentally harmful mode of transport even if it holds the 80% of global trade. According to Bickel et al. (2006) the basic activity of maritime transport is "navigation" which includes transportation, maintenance, embarkation and disembarkation of people and goods. Due to those activities shipping produces emissions and other dangerous pollutants. Some more activities included in shipping sector are manufacture, conservation, cleansing and decomposition of ships as well as the manufacture and conservation of the port, which cause emissions, hazardous air pollutants (HAPs) (Hayman et al. 2000) and even unburned hydrocarbon (UHC), or heavy metals (in cases of large amendments in ships). In further, some of those dangerous pollutants contribute to global warming and green house effects and even cause acidification. Moreover, it seems that port operations such as power provision to vessels, trains and cargo transportation are also responsible for the same hazardous emissions. It is essential to underline that probably the close to ports areas are inhabited by low-income people, something that needs primary importance concerns.

The footprint of shipping on the environment has many different aspects. More specifically, emissions can cause severe healthy problems such as increase of cancer, increase of respiratory deceases, especially to children and be responsible for increased mortality rates. Also, shipping affects severely the biodiversity and downgrading of coastal areas. In particular according to Schreier et al. (2006) ship emissions are responsible for negative effects in clouds, the aerosol effect. In addition emissions from ships can be transferred easily through the air to far distances (Trozzi, 2003). Corbett & Fishbeck (1998) concluded to the fact that ocean-going vessels are significantly responsible for the total emissions of nitrogen, sulphur and less contributors to total carbon dioxide, particulate matters, hydrocarbon (HCs) and carbon oxide. They also found that 80% of the total vessels are either anchored, either close to coasts (Corbett et al. (1999), p. 3462), specifically 400 km (248 miles) (IMO, 2000 and Corbett et al 1999). Consequently, most of the emissions released to the atmosphere take place close to land. It is important to refer that not only air pollution is caused by the emissions but also soil pollution (rivers, lakes and soil can be affected). The study showed that the northern hemisphere suffers more and the most negatively influenced areas are North Atlantic and Pacific Rim.

In 2000, IMO showed that the ocean-going ships caused, in 1996, the 1.8% of the total CO_2 emissions. Corbett, Koehler (2003) and Eyring et al. (2005) also concluded that maritime transportation is responsible for 30% of the total NOx emissions and 9% of the global level of SOx emissions.
Further, in order to evaluate the impact on the environment, except the above aspects, accidental or illegal activities should also be taken into consideration. Shipping GHG emissions reach the level of just 2.7% of the worldwide level of greenhouse gases, close to the percentage that Germany produces. Additionally, ships contribute to black carbon, which constitutes 10% of the total Particulate Matters that are released in the air. Black carbon is responsible for global warming, ice melting phenomenon and climate change. Shipping sector contributes almost 2% of the total levels of black carbon globally (Lauer et al. 2007). The CO_2 emissions that vessels release are in significantly lower levels than those emitted of rail and road transportation. In particular, the emissions from shipping sector do not exceed 60 g CO_2/ton*km while rail and road transportation can release up to 120 g CO_2/ton*km and 250 g CO_2/ton*km respectively. In 2007 (according to IMO MEPC58/INF.6, IMO GHG Study), shipping was responsible for about 847 million ton, while road transportation at the same period possessed 21.3% of global CO_2 emissions. The forecasted scenarios in 2050, based on the assumption that no actions to address emission's issue took place, estimated that 4.817 mill ton or 2.955 mill ton of CO_2 emissions will be released to the atmosphere (IMO MEPC59 Agenda item 4). Moreover, in 2007 ICCT estimated the emissions level in 2050. The study showed in case that ship's contribution to global emissions continues in the same levels, the NOx emissions are estimated to increase by 30%, SOx by 18%, CO_2 by 3% and PM emissions almost doubled. However, the increased expected rates can be a result of the attempts to reduce SOx and NOx land-based emissions.

2.3.1 Regulating Emissions

There are many technological improvements that could be taken in advantage and shipping could become even more eco-friendly sector. As well, it seems essential to adopt systems that improve the shipping's footprint on the environment and regulate shipping sector.

Initially, the current regulation in international level is covered by IMO, UNFCC and WTO with conventions, market based measures and ECAs (covers the issue of NOx and SOx emissions). In regional level in terms of USA and EU coastguards, Emissions Trading Schemes (ETS) and Port State Control could provide safety tools. In national level it seems to be more difficult, but Lobby groups can have significant positive impacts though. The key areas of regulation in shipping are the time horizon of its application, the different kinds of measure such as specifications, taxation or "cap and trade" system. Currently, the IMO Convention about protecting the environment from the maritime sector is the International Convention for the Prevention of Pollution from Ships (MARPOL 1973/1978) and MEPC an amendment in MARPOL. The Convention is based on articles of control and implementation of the regulations. There are 6 Annexes regulate the different aspects of pollution by maritime sector. Annex I and II are mandatory for the Member States that adopt MARPOL. Annex VI was established in 2005 by 60 States which cover almost 84% of the world's shipping tonnage and regulated the anticipation of air pollution by NOx emissions and SOx of ships. Also, IMO standards are usually reported as Tier I-III standards. The limitations that the IMO imposes seem to be less strict that it should be, consequently the advantages as well as the costs of the IMO strategy implementation, are insignificant.

Annex VI sets two dimensions in terms of fuel quality: 1) International level of the Convention requirements and 2) more strict requirements adopted by vessels in Emission Control Areas (ECA). According to Regulation 12 of MEPC 58/22 "an Emission Control Area shall be any sea area, including any port area, designated by the Organization”. Moreover, in Annex VI is expected that the global sulphur level should be decreased by 3.5% from 2012 and thereafter 0.5% gradually from 2013. In addition, IMO promoted the NOx emissions reduction by suggesting strict controls to vessels after 2016 and forbidden the emissions of ozone depleting substances, including chlorofluorocarbons (CFCs).

Currently, it also seems that Kyoto Protocol and United Nations Framework Convention on Climate Change (UNFCCC) were approaching the issue of decrease of maritime transport emissions in a controversial way. In a meeting in Copenhagen, a potential solution was suggested by UNFCCC; an international upper limit on bunker fuels. A different solution could also be each vessel to have different liabilities only according to its size and route, and not according to its nationality (Faber and Rensema, 2008). As a result the expected growth rate of the developing countries would not affect the strategies set. About GHG issue (specifically about CO_2 emissions) IMO promoted effective efforts and plans for new technologies and innovation towards sustainable environmental growth.

The EU actions about mitigating air pollution are regulated under the Directive 1999/32/EC25, which contains efforts for decreasing the sulphur level of specific fuels, in EU seas. More specifically, IMO has strengthened the limit of 1.5% on sulphur level in maritime transportation in Emission Control Areas. In Copenhagen the “European Commission Communication” established policy towards an efficient market. In particular in order to stabilize 2°C the temperature change up to 2050, GHG emissions should be reduced 59% as compared to levels of 1990 (adapted from 2nd IMO Report, 2009, pg.1). The Market-Based measures could be an effective option. It is interesting to refer that the EU goals up to 2020 focused on mitigating GHG 20% and 20% "renewable" energy consumption.

Moreover, regarding the GHG emissions from maritime transport in the EU, Emission Trading Scheme is an effective option. In particular, the scheme offers among others flexibility and potential ground to develop strategies in order to decrease the level of air pollution. However, there is uncertainty for the future strategies and as a result fluctuation in the market and instability could occur. In order to develop the Emission Trading Scheme for shipping globally, initially, has to be in line with the International Law of the Sea and specifically with the United Nations Convention on the Law of the Sea, 1982 (UNCLOS).

Last but not least, to mitigate and control emissions EU has proposed the “Maritime Emission Trading System” (METS) which will play a significant role. It allows ships to buy rights of emissions. Each ship would have an account and the emissions would be sold by an international unit. Moreover, a fund would be raised from the emission transactions, which would contribute to the reduction of CO_2 emissions. As a result this system will be highly connected with the carbon prices. In addition, it is likely shipping to be part of the EU METS. In order to discuss the inclusion of shipping in METS, EU quotes that “the EU will continue to pursue an international agreement through IMO and the UNFCCC’’. (Communication COM May 2010). ETS seems to be a tool without obstacles to the sector, flexible, maintained by the industry, gives potential opportunities for internationally expansion and it did not cause any high costs although it seems its performing to be under consideration. Although there are obstacles such as the application in the EU level due to the necessity of emissions calculations etc., it seems that the cost generated would be low, the performance in good levels and it will cover short/medium time horizon with regional characteristics. The processes in shipping regulations as it seems until now are not fast developing; consequently it is difficult to forecast the effects of emission reduction as many economical-political key areas are unknown.

2.3.2 Type of emissions, negative effects and potential solutions

As the currently regulatory framework and proposed actions has been presented, below it follows the procedure and measures required in order to analyse the issue of emissions, analysis on the types of emissions released, their negative effects and their potential solutions.

Each type of emissions requires a different regional analysis; in particular CO_2 requires global level of analysis where NOx and SOx requires a regional level analysis. In order to evaluate emissions, bottom-up approach, top down approach and a mixture of those is used. It is also essential to specify two dimensions where the emissions took place and the level of those. In the bottom-up analysis, emissions from each vessel are evaluated and in order to estimate in global level, the separate results are combined. Conversely, in a top-down approach the different characteristics of each level are not used, but the total level of emissions is calculated in a specific location. The criteria for choosing the most appropriate approach are the variety and the volume of date available. The data required are related with technical issues such as type, size, type of ship engines, fuel consumption, fuel category or engine's age and engines' working hours. The latter plays a significant role in evaluating emissions. The most important tools are separated between the "command and control" and the "economic incentive based" instruments. More specifically the different criterion could be cost-effectiveness, long run effects, dynamic efficiency, ancillary benefits, equity in terms of distribution of wealth, flexibility by meaning the ability of quick implementation, costs in case of using inaccurate data and data required and the potential cost gathering them.

Following is the analysis of the emissions released by shipping sector and its potential solutions according to Annex VI.
The emissions of SOx are regulated by the Directive 2005/33/EC. Ships generate emissions of sulphur oxides (SOx) as a result of the combusting fuel used. Emissions of SOx are extremely influenced by the fuel used and its relative sulphur content. Also the existence of SOx emissions is connected with the emissions of particulate matter (PM). Moreover, the SOx could affect hazardous areas near the coast and could even cause acid rain. Firstly the most efficient method to limit sulphur emissions (SOx) is to reduce sulphur content in fuels. The limitation set by European Commission is 0.1% of marine fuels. Also, combustion modification which uses injections of limestone can reduce the sulphur levels by 50-60%. By using the Dual-Fuel-Engines system, vessels can use Natural Gas instead of heavy fuels in coastal areas. Other alternative reducing SOx emissions could be the waste heat recovery systems that convert the energy from exhaust gases into electrical power which could be usable for ship's operational functions, achieving less fuel consumption, consequently less SOx emissions. Moreover, scrubbing is one of the most effective options, as achieves almost 99% mitigation of the SOx emissions and 85% of the PM emissions, without affecting CO_2 emissions. The scrubbing methods that exist are namely "Sea Water Scrubbing" and "Fresh Water Scrubbing". The first option is ideal because of its efficient results. On the other hand in the second option there is the unknown result about the purification of the water which is discharged to the sea. Until the date that the report was written, scrubbing could not ensure its application in all sections of the environment, meaning port areas or shallow waters etc.

Emissions of oxides of nitrogen (NOx) are also legally set from the MARPOL 73/78 Annex VI. The emissions of NOx, as sulphur oxides (SOx), are released in the environment, because of the fuel combustion. The NOx emissions could affect negatively the level of air pollution as they damage the environment through acidification as well as human health, especially in coastal areas and ports. However, there are several ways to contribute to the reduction of NOx. In order to reduce these emissions the combustion system could be enhanced by Miller Cycle and two-Stage Turbo charging. In addition, another method that could be used is called "Internal Engine Modification", which refers to the changes in the combustion system of a ship. The IEM systems include "retard injection" which can reduce by 30% the NOx emissions but without avoiding the risk of reducing efficiency (Wartsila Corporation, 2004). Water injections are also used in order to reduce the combustion temperature and reduce NOx emissions by 50-60% {by using 40-70 water/fuel ratio (Sarvi, 2004)}. Moreover the "Humid Air Motor" system uses water to add to combustion air and can reach 80% reduction in NOx emissions (Eyring et al., 2005b). Other technologies such as “Exhaust Gas after Treatment Technologies” can effectively decrease emissions from engines. “Waste heat recovery systems” can also diminish the levels of NOx. Finally through systems of “Electronically Controlled Camshaft less Engines”, “Turbochargers”, “common rail technology”, “valve control” and “optimised combustion processes” can all diminish the levels of NOx emissions from ships. A competitive alternative solution could be the "Plasma Reduction Systems" which transforms electrical power into electronic energy. The adoption of such a system can generate up to 97% reduction in NOx emissions.

Regarding CO_2 emissions, the IMO (2009) report underlines that the adoption of measures that can effectively contribute to the reduction of them, can decrease by 25-75% the emissions comparing with the current levels. The report also showed that the emissions of shipping would in long term contribute significantly to the global warming and to climate change. By 2050, the CO_2 emissions from shipping should be responsible for 12-18% of the total CO_2 emissions. Some interesting statistical information about CO_2 emissions are the expected increase by 126-218% in 2050.
It is significantly important to mention that emissions of carbon dioxide (CO_2) are not regulated by any international convention. The CO_2 emissions are released to the atmosphere as a result of the thermal combustion of fuel. The greenhouse effect and global warming, one of the major problems the environment faces are exacerbated by the continuous emissions of carbon dioxide. As a result, reducing CO_2 emissions in a significant level would contribute to the climate improvement.
A potential solution to mitigate CO_2 emissions, suggest firstly that shipping could be adjusted to slower energy consumption (e.g. slower traffic). Secondly, ships could change the type of fuel, more specifically to replace oil fuel with Natural Gas. Also a system of “Hybrid Auxiliary Power” could be installed, which has as a result an important level of reduction of the emissions of CO_2, NOx and particulates matters. This system uses fuel cell, diesel generating set and batteries, even solar and wind power in order to combine them in the most efficient way, succeeding a satisfying level of energy consumption. Moreover, ships could install alternative propulsion, a kite which can take advantage of the wind power and can save up to 20% of the fuels. A more complex solution, as it requires new ways of ship designing and operation is Waste Heat recovery. This system allows reaching 12% of fuel savings (consequently CO_2). Moreover, ship-owners could install “rudders” that would generate 5% of the ships resistance. This method could reach fuel savings up to 2-5%. Finally, ships could gain efficiency through “Cold-Ironing”, a system that introduces the idea of providing ships with “shore-side” electrical power when they are anchored in the port. An extensively report on this matters will follow later on the study.

It is also important to underline that emissions are strongly depended on the vessel's speed. One knot reduction in speed can increase by 11% the efficiency. In IMO 2009 was promoted that in cases of bad weather, it is suggested ships to choose a longer but calmer seaway even if the shorter distance in other cases is more cost-efficient. Also, the use of “autopilot adjustment” could save energy consumption while adjusting stability of the vessel. Finally it should be underlined that spreading the culture of energy saving by incentives, monetary or not and training the crew would significantly improve the energy consumption and efficiency rates.

To continue, as it has already been mentioned market-based measures could contribute locally as well as globally to the emission mitigation. In terms of locally market-based actions, variable dues can be established according to the low-emissions and the performance of the vessels. In terms of globally market-based strategies, a cap and trade system could be established. A successful implementation of the first strategy took place in Sweden were the goal was to mitigate NOx and SOx emissions by 75% in ten years and it was a voluntary program among ports in Sweden. In particular, according to each vessel's gross tonnage "baseline dues" were established and according to each vessel's emission efficiency the dues were decreasing. After 8 years and 44 vessels which had installed emission control systems, 87% mitigation of NOx emissions was achieved. This strategy has become commonly adopted the last ten years because of its flexibility on the level of reduction and the place of the system implementation. However, there are obstacles in establishing the cap and trade strategy globally. Also it seems that this approach is more suitable for CO_2 emissions and not for non-CO_2 GHG emissions.
Nowadays major shipping companies adopt environmentally friendly policies and green shipping practises (GSP) in order to achieve less harmful maritime transportation. In addition, companies choose "greener" policies in order to gain efficient supply chains (Wong et al. 2009a, Yang et al. 2009a). It is important to refer that the environmental strategies are not common among shipping companies and there is unawareness as far as it concerns the incentives used behind the "green" policies. Moreover it seems that the existing studies do not provide any information about the different forces from the various stakeholders ranging from shippers to governments which form the environmental strategies of the shipping sector. In particular, the parts that can form "green" strategies promoted could be either institutions with regulatory power or clients' businesses, either international trade forces. In further, Green Shipping Practices contribute significantly to improvement of competitiveness among major international trade centers, such as Hong Kong's port. In micro economic level GSP could help shipping firms to optimize their performance while protecting the environment. According to studies (Lai et al., 2010a) shipping firms are increasingly shift their actions to voluntarily strategies addressing sustainable economic development and environmental conservation. However, the lack of strong incentives in order to adopt eco-friendly policies lead to potential opportunities for further development. It is important to refer some of the major shipping companies that have already adopted GSP. In particular, namely APL, K Line, NYK Lines and Maersk are members of "Clean Cargo Working Group" which focuses on creating a "clean and sustainable world". The objectives of the Group are in line with sustainable economic development, by sharing decision results, data, clients’ expectations, know-how and awareness among the

stakeholders. Such policies and systems developed could accelerate the procedures for meeting the goals set.

According to Smith and Grim (1987), companies function in a "self-interest seeking manner to maximize their financial gains". In contradiction, it seems that firms perform in an environmentally responsible way not only by economic incentives but also by factors ranging from regulatory measures to international trade forces. According to Guide and Van Wassenhove (2009), "Balancing economic and environmental performance has become increasingly important for organizations facing competitive, regulatory and community pressures". The issues that every nation has to examine in order to be in line with environmental actions, are how to develop effective policies in order to take into account environmental protection and how to generate profit from their functions by mitigating their impacts on the environment (Cheng and Tsai, 2009).
Actual examples in the market constitute of the following strategies that some shipping companies implemented. In particular, in 2008, A.P. Moller-Maersk Group firstly established the Heat Recovery System which could save up to 10% of fuel consumption while saving half million CO_2 emissions per year. Moreover, Maersk adopted the "Voyage Efficiency System" which can effectively choose the most efficient vessel's path in order to optimize fuel consumption and consequently to reduce emissions. In addition, Maersk installed the software system called "Quality and Energy efficiency in Storage and Transport". It allows saving up to 50% fuel consumption by cooling in an effective way the containers. In addition, it promoted an environmentally responsible culture by obtaining ISO 14001, reduced significantly the volume of papers by installing "End-to-End EDI Solutions" (automatically informs from clients to business partners) and installed eco-friendly facilities, material (eliminated the use of chlorofluorocarbon) and equipment in its vessels. In addition, Maersk installed a "pilot test" to use fuels relieved from hazardous components. As a result, the pilot system showed an 87% per year decrease in PM, a 95% decrease in SOx emissions and 12% decrease in NOx emissions. Finally, NYK Group promoted the "Save Bunker Innovation" campaign which focuses on reducing fuel consumption and eliminating CO_2 emissions. NYK promoted the "FUELNAVI" system which could provide information in real-time about fuel consumption efficiency according to the distance covered. Also it can provide details about the impact of weather on fuel consumption and about the speed allocation in streams.

It is a fact that firms can easier adopt GSP policies when industrial practices are developed by ICS or IMO in order to provide guidance to environmentally responsibly actions. In addition, companies are easier compliant with GSP when they are functioning under "institutionalized norms". The firms are forced to follow the environmental specifications required in order to avoid the possibility of losing business due to their irresponsibility in environmental issues and their opponents' potential environmental actions. Further, another incentive that leads companies to GSP policies is the environmental requirements from their customers. Customers identify the potential increase of performance in the shipping activities after establishing a "greener culture". Also there is significant evidence that adopting green culture can improve performance (Lai et al., 2010a), that will be translated to clients as higher return. Finally, shipping companies which adopt GSP can gain environmental benefits but also productivity efficiency as the advantages that firms can gain from environmental practices and establishing GSP’s are increasingly being recognized (Lun et al, 2010b).

Chapter 3 Regulations & Methods for Eco-Technology

3.1 Energy Efficient Design Index (EEDI)

The EEDI is an index proposed by IMO to control the CO_2 emissions of the shipping sector. Its mandatory application (since January of 2013) is met in new vessels and leads to improvement of energy efficiency. The EEDI is applicable in ships that are over 400 gross tones and is calculated according to ship type and size. The EEDI has to be lower or at least equal with the required EEDI which is calculated as follows:

Required EEDI = (1-x/100) * Reference line value

Reference line value of bulk ships =961.79 * (DWT of the ship) $^{-0.477}$

In order EEDI as well as the NOx and SOx emissions to be mitigated in the long term, there are three phases that extend over year 2025 and promote the levels of the reduction to be 30% in the end of the analyzed period.

According to the IMO estimations, the adoption of the EEDI and the Ship Energy Efficiency Management Plan (SEEMP) and assuming 9%-16% reduction by 2020, will lead to CO_2 emissions reduction by 180 million tons. By 2030, the emissions reduction is estimated to reach 390 million tons annually and in particular this means 17% to 25% reduction comparing with the current conditions. The SEEMP refers to guidelines for the most effective strategies for fuel efficiency that can be implemented by new-built and existing ships. In addition, the IMO has estimated that adoption of EEDI and SEEMP will result to annual fuel cost savings of about $50 billion in 2020 and $200 billion in 2030. (Rodrigo De Larrucea, Jaime. "ENERGY EFFICIENCY DESIGN INDEX (EEDI).")
More specifically the equation of EEDI is given by the formula:

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

The equation calculates the CO_2 emissions generated as a result from ship operations. It provides information about ship contribution in CO_2 per ton/n.m to total CO_2 emissions. The 4 terms used in the first line of EEDI equation are the emissions due to main engine, emissions due to auxiliary engines, motors emissions and the energy saving technologies such as waste heat recovery systems and use of wind and solar power. The 4 factors evaluate the CO_2 produced, the fuel consumption, and carbon factor for a specific type of fuel. In the bottom line of the equation the factors actually represent the transport work, which is calculated by multiplying the ship's speed at the maximum load condition and the capacity of the ship (dwt), as designed. In further, there are factors used in order to improve or better to correct the equation. In particular, these are ship design factors, factors representing weather conditions, factors representing obligatory structural improvements or factor in case the ship has been built in line with Common Structural Rules (CSR).

The technical methods used in order to reduce the EEDI of the vessels are categorized in four themes. In particular the actions are analyzed under the scope of design, technology, operation and fuels. Initially, the design of a vessel can improve its capacity while ensuring safety rules and lighter materials to reduce vessels weight. In addition, it is proven that by hull optimization, resistance is reduced. Moreover, the propulsion optimization can improve the propeller efficiency and consequently to reduce noise pollution, vibration and fuel consumption. Regarding the alternative technologies, the focus on renewable energy plays a significant part as wind and solar power can contribute to EEDI reduction. In terms of technology, vessels speed and performance play important role, as a result the choice of engines is a basic point. As concerns the ships operation, the key point is the reduction of ship speed. Slow seaming is one of the most contributing actions in CO_2 emissions reduction. However, all these methods will be presented extensively further.

3.2 Ballast Water Management

In order ships to be stable and balanced, ballast water (BW) system is essential to be adopted. According to the weight of the cargo loaded, ballast water is pumped in or out. The main problem is that the ballast water carries marine organisms (eggs, aquatic plants and animals, etc) that are finally displaced by the discharge of ballast. Even if a proportion of those cannot survive in the conditions in the vessel, a great part of those can be expanded and consequently harm not only the place the water was loaded but also the environment of the displacement area. The impacts of the ballast water displacement are obvious on the negative impulse on the biodiversity, on the underwater flora and fauna and maritime sectors such as fishing even human health.

In order ballast water treatment to have an efficient solution, IMO and the countries members proposed the voluntary guidelines to be globally obligated in the future. Ballast water treatment tools proposed by IMO contain (Champ, 2002;Gollasch et al., 2007; IMO, 2004) areas in ports where hazardous organisms are known to exist in order to eliminate the volume of organisms contained in ballast, purifying ballast tanks, reducing the unnecessary discarded ballast and exchanging ballast water at sea with open ocean water. Moreover, IMO promoted required standards {Annex 4, Resolution MEPC.174 (58), Regulation D2}, in particular the discarded ballast water should contain less than 10 viable organisms between 10 and 50 μm/mL and less than 10 viable organisms over 50 μm/m3. In addition, the convention contains standards for microorganisms that should meet those standards. In particular, Toxicogenic *Vibrio cholerae* (Serotypes O1 and O139) should be less than 1 colony forming unit (cfu) per

100 mL or <1 cfu/gram (wet weight)zooplankton samples, *Escherichia* coli should be less than 250 cfu/100mL, and Intestinal *Enterococci* should be less than 100 cfu/100mL (IMO, 2004, Tang et al., 2006a, 2006b; Wright et al., 2007a, 2007b).

The technologies for ballast water treatment that are still developing can be categorized in mechanical processes such as filtration and separation, physical processes such as sterilization by ozone and chemical processes such as use of biocides or any combinations of the above.

The shipping sector is ready for installing the existing technologies which would have been mentioned, if they meet the international rules. The difficulties could be met due to the huge volume of ballast water required by vessels, the vessels design restrictions and the potential negative influence that technologies have on the vessels operations. In particular, any ballast water treatment method should be cost-efficient in terms of monetary units, in line with ship's functions, safe for the rest of organisms and with eco-friendly characteristics as well as approved by international authorized organization.

The existing technologies constitute a wide range of solutions according to the vessel's features but methods for the treatment of huge volumes of water are still developing. The most widely adopted tool for ballast water treatment is Ballast Water Exchange at sea. More specifically, it can be achieved exchange of the 95% of ballast with open ocean water. However, the effectiveness of this system has not been proven as many organisms can remain in the ballast water. According to the IMO proposals, sequential exchange of ballast water can achieve even 100% elimination of the organisms in ballast. A disadvantage that could occur is that an error in the procedure could cause stability loss. Also, according to the IMO continuous exchange (a continuous process of exchanging ballast water with ocean water) is suggested where the effectiveness reaches levels of 95%. In further, the most efficient way of treating ballast water is the placement of the latter at least 200 miles from coast and in depth of at least 200 m. However, this method is limited by ships' safety restrictions and is less than 100% efficient in eliminating the organisms as well as it requires hours even days to be completed. The latter shows that this method can be inefficient for short voyages. The Ballast Water Exchange exposes dangerously the vessel in the weather conditions and still has not proved its effectiveness; consequently this method is not always possible to be executed. Finally, there are three types of BWE that can take place; the empty-refill, the flow-through and the combination. A study conducted in 68 tankers showed that BWE is inadequate for eliminating completely organisms from ballast water.

As the physical methods are unable to eliminate the organisms completely and as the chemical methods require a previous step of cleansing in order to achieve a satisfying result, the combinations of those is suggested. According to the National Research Council (1996) filtration is the most efficient developing technology and additionally, filtration following by UV constitutes one of the most effective existing methods for treating ballast water. By adopting granular filtration, the elimination of the organisms that are larger than 50μm can be achieved .However, except that this method has low filtration rate, it is not cost-effective due to its significant requirements in terms of space. Between filtration, heat and ballast water exchange, the latter has the most desired results. Moreover, adopting crumb rubbers to filter wastewater can lead to higher filtration rates, less space requirements as well as longer filter time. As the crumb rubber method has different results from granular filtration, it seems that the latter cannot effectively be adapted to crumb rubber filtration.

Furthermore, low temperature treatment, which contains heating of ballast water in less than 45 ^{o}C and about 30-80 hours. As a result, this method is inefficient for short voyages and it likely to increase the corrosion. A variation of this method could be the heating of the ballast water in 40-80 ^{o}C resulting in gaining significant time. It is essential to underline the energy costs and the negative influence on the environment with the heating of such huge amounts of water as well as the impulse on the engines of the vessel. It is obvious that less heating time leads to less energy costs.

Regarding the chemical methods, IMO suggested the adoption of active substances in order to mitigate hazardous organisms that could exist in ballast. The active substances could be a virus or a fungus, capable of eliminating specific hazardous organisms. However, the adoption of such a system in national level should be initially in line with international rules as well as to be regulated under national regulations. Another method that could be established is ozonation, which its treatment does not require any chemicals stored to the vessel neither to the port. Moreover, ballast water treatment requires toxicity in order to eliminate effectively harmful organisms, threatening in this way the maritime life in coastal areas. It is a fact that the combination of sonication, ozone and hydrogen peroxide can be used successfully to inactivate a model bacterium (Vibrio alginolyticus). Also, the UV/Ag-TiO2/O3 treatment is a procedure of eliminating species during the ballasting or de-ballasting process which has significant efficiency in ballast water treatment.

Furthermore, the PERACLEAN® Ocean chemical method is proposed that can efficiently inactivate hazardous organisms and bacteria in ballast water while averts the multiplication of the organisms. Also, it should be highlighted that PERACLEAN® constitutes a method which is efficient under a wide range of temperature and salinity conditions. However, as a result of a study conducted by Gregg and Hallegraeff in 2007 the use of other biocides such as Vibrex®, Ocean and SeaKleen® even PERACLEAN® is restricted by costs, biological efficiency and potential residual toxicity of the discarded ballast water.

To conclude, the arrangement of the problem is subject under various researchers and institutions such as IMO which regulates international trade in international waters. It is a fact that none of the methods of ballast water treatment has showed to be simultaneously 100% cost effective, safe and applicable on-board ships. An effective option could be the combined establishment of various ballast water treatments in order to achieve effectiveness and to meet the IMO standards. Finally, it seems to be essential the provision by governments and authorized organizations incentives in order to lead actions towards actions for ballast water treatment.

3.3 Energy Saving Devices (ESD)

Many different devices have been designed the past few years but most of them were rejected except propeller ducts. The devises were rejected mainly due to structural failure and due to vibration generated. Also, other factor that contributed to their rejection was the lack of accuracy in measuring abilities. In particular, the devices could not be confirmed in sea trials and it was impossible to ensure their financial feasibility. Moreover, their lack of transparency of savings in real functional conditions contributed to their failure. More specifically, the actual conditions the ships were operating were far beyond assumed in the ESD calculations. Finally, those devices failed due to their lack of specification in device values in terms of design. Also, the fact that shipping sector is extremely fragmented contributed to the devices failure.

However, the last years knowledge about actual factors that affect ship efficiency, such as the water resistance issues ,was used in order to upgrade the design of the devices Also, simulations such as Computational Fluid Dynamics (CFD) were developed in order to evaluate the flow characteristics as well as the potential opportunities for propulsion efficiency improvements. Moreover, systems of on-board measures and monitoring systems are now providing information about ship performance and ships operational characteristics. The operational characteristics contribute to the formation of ships operational profile which is essential for the optimal ESD choice. Finally, the technique of Finite Element Analysis (FEA) combined with agreed acceptable cavitation in the propeller, contributes to the evaluation of the devices.

The selection of the device should be based on the specific characteristics of each vessel as well as the operational profile. The selection process is suggested to include:

1. Select retrofit using information provided by the owner or supplier
2. Utilize by applying CFD and check viability
3. Model test to confirm
4. Verification

In particular, the first step includes the collection of the information about:

1. the type and characteristics of the hull shape
2. the vessel speed
3. the variations in draft/trim and
4. the relevant operational conditions

The second step of applying CFD is important due to benefits offered. Initially, by installing ESD leads immediately to energy and fuel saving while the ESD is adopted based on ship operational profile. Consequently, it is expected, the results to be according to the model tests.

The CFD provide also information about the characteristics of the flow close to propeller, which will contribute to the reformation of propeller itself. Moreover, the CFD compares in a model-scale the results and full-scale results and consequently, the confusion that occurs between results of the different model tests. In further, it is interesting to underline that CFD evaluation is appropriate for all geometrical devices. Finally, even if solutions based on specified lubrication systems could not be in line with CFD function, for air lubrication system CFD are appropriate.

The third step includes the analysis of model testing with CFD calculation in order to produce the predicted return of the investment. The model test offers verification of CFD functions and numerical information about savings. The combination of model test and CFD calculation leads to more accurate answers about the returns. Finally, the last part of the decision process includes the examination of the performance in full-scale trials. In particular, the most appropriate solution is the comparison of sister ships, both cleaned before the standardized trial.

At this point, it is necessary to mention that the use of the energy saving devices takes place in the propulsion system, the hull and the main engine of the vessel. Therefore, we will study the ESD as concerns the following categories:

1. Propulsion efficiency
2. Hull optimization
3. Main engine

3.3.1 Propulsion efficiency

The propulsion efficiency η_D is the ratio of the effective power (hull resistance times speed) to the power absorbed by the propulsion system. The propulsion efficiency is separated to propeller efficiency η_p and hull efficiency η_H (propulsion-hull interaction) while the propeller efficiency is divided to open-water efficiency η_{po} (is affected by rotation, friction and axial losses) and the "relative-rotative" efficiency η_R.

The propulsion efficiency is defined as follows:

$$\frac{P_E}{P_D} = \eta_D = \frac{JK_{TO}}{2\pi K_{QO}} * \frac{K_{QO}K_T}{K_Q K_{To}} * \frac{1-t}{1-w}$$

$$(\eta_{\rho o}) \quad (\eta_R) \quad (\eta_H)$$

The ''relative-rotative'' efficiency is defined as the change in propeller efficiency when going from the open-water to the behind-ship condition. It is affected by the shape and size of the hub and also provides information about wake adaptation

The aim of the energy saving devices is to strengthen the flow in the propeller in order to improve propulsion efficiency and consequently, reduce energy losses. It is essential, for the establishment of those devices in the market to be easily adopted, easy to be conserved, to require low installation costs and the most important that it really works.

One example of an ESD regarding the propulsion efficiency is the Pre-swirl stator (PSS), which has been developed the last 10 years. The PSS is a device placed in front of the propeller and its aim is to produce pre-swirl flows which can effectively interrelate with the propeller in order to improve propulsion efficiency and to mitigate required power. In a wide range of vessels the PSS system is installed with four blades which should have the same diameter with propeller diameter. The propulsion energy savings which this devise achieves according to model tests as well as sea trials, reach the levels of 4%. In addition, it seems that the potential-flow based method and RANS code to be a sufficiently integrated and accurate method for forecasting the thrust as well as rotation rate for the propeller in order to define the optimal design. By SHIPFLOW two-stage simulation, the influence of PSS on propulsion efficiency as well as the angle variations of stator blade pitch can be analyzed. Moreover, the lift duo to stator blade leads to change of flow direction. The results in terms of energy efficiency show that 5% to 6% energy gain is reachable by the best PSS. Also, it is essential to refer that after detailed analysis the SHIPFLOW simulation properly predicted the ranking among the examined PSS configurations.

Another example is the semicircular duct type energy saving device which has been presented by IHI Marine United Inc. According to model tests this device comparing with the typical circular duct achieves 5% reduction in power consumption. The duct is placed in front of the propeller in specific positions as a result, the flow field in propeller is improved and also the generation of thrust is enhanced. Its contribution includes in particular, ship resistance decrease, enhanced thrust creation, improvement of the wake gain as well as improvement of propeller efficiency. In addition, the enhanced thrust is achieved by placing the duct where the angle of a diagonal flow is large. Also, according to the design of the duct, its diameter is usually 0.7 times of the propeller diameter to forward low speed wake flow. According to the results of a stern flow field measurement, it was highlighted that the upper part of the duct is important to be effective. The tests, including self-propulsion and a resistance test, were conducted by IHI assuming a 300,000 ton crude oil tanker to measure circular and semicircular duct effectiveness. In the test the Effective Horse Power (HSP) and the Brake Horse Power (BHP) were calculated. Initially, it has been found that the installation of duct gains almost 3% energy efficiency, as the resistance was reduced significantly. Also, the results showed that the semi-circular duct contribute to energy efficiency more than the circular duct. In particular, the semi-circular duct contributed to 3.5% in energy efficiency where the circular duct contributed to 2%. The self-propulsion test showed that the factor which is linked with the upper side of the duct contributes significantly more to energy efficiency, as its improvement ratio is almost 1.5% while the ratio of the self-propulsion factors of circular duct are less than 0.5% .

In order to design an efficient semicircular duct, it is important to underline the factors that the energy efficiency performance depends on. In particular, (i) mounting placement of duct, (ii) angle of space of duct and (iii) the length of duct. More specifically, as the length of the duct increases, the energy efficiency is also improving.

Finally, according to studies on the structural strength of the duct, which was conducted with finite element analysis method (FEM) it has been proved that the designed duct structure has adequate strength and it is appropriate in terms of safety. These results are important as rough weather conditions and other forces at the stage of turning motion add loads that could raise safety issues. It is obvious, that due to the necessity of fuel consumption reduction, the introduction of semicircular duct in the market is essential.

To conclude, propulsion efficiency can also be achieved by changing the propellers of the vessel to high efficiency propellers. The latter can generate from 3% to 5% savings in propulsion fuel consumption compared to the conventional ones. They can be applicable to all types of ships in new building or as retrofits and their cost varies from medium to low according to the device. This kind of optimization takes place in the design stage while it is also suggested the optimization of hydrodynamic performance for even the off-design conditions that a ship could face. It is commonly accepted that larger diameter propellers with less sharp edges are more efficient than the smaller ones. The different propellers are (ABS, 2013):

1. *Controllable Pitch Propellers (CPPs)*

In contrast with fixed-pitch propellers (FPP), the controllable-pitch propellers have less efficient performance when used at constant RPM. However, CPP wheels gain more performance than FPPs in out of the design circumstances when the RPM is variable to counterpart the CPP's highest performance. By a reset of CPP propeller efficiency maximization is achieved which can be useful when the vessel functions in slow-steaming conditions.

2. *Ducted Propellers*

The ducted propellers are functioning in a cylindrical duct and their aim is to accelerate or decelerate the flow around propellers. The decelerating ducts usually just control cavitation while accelerating ducts meliorate propulsion features of low speed vessels. The significant power is generated by the lift due to the accelerating flow, is counterforced by the supplementary pull created by the duct itself which increases as ship speed increases.

3. *Propellers with End-plates and Kappel Propellers*

These kinds of propellers which are characterized by modified sharp edges tip geometries focus on mitigating tip vortex and increase the total propeller efficiency. In particular, while Kappel propellers mitigates tip vortex, the end-plates expands a chord with a thin plate towards the pressure side. It is a fact that the efficiency generated is significant. Also, these devises are appropriate for combining them with other efficiency-gaining devices.

4. *Contra-rotating and Overlapping Propellers*

These propellers improve the efficiency by taking in advantage the rotational flow, like pre-swirl functions. The Overlapping Propellers, the two propellers do not have the same axis in contrast with Contra-rotating propellers. In effect, Contra-rotating propellers are more commonly used and lately they have been applied on some kinds of azimuthing and podded propulsion systems.

5. *Podded and Azimuthing Propulsion*

The combination of steering and propulsion operations leads to better results of both as significant efficiency gains can be generated. However, high costs, limited power offered and some technical problems due to their complication are the obstacles that restrict their optimization. The podded propulsion is power-driven by electrical motor in the screw while azimuthing thrusters are powered by an L or a Z shaft line, where the engine is placed in the vessel. In the last decade, the pods were mainly installed in passenger ships and ferries while the azimuthing thrusters were usually used on offshore floating installation or tugs.

3.3.2 Hull form optimization

In order ship-owners to achieve less fuel consumption on their ships, they also focus on hull form optimization, meaning that their goal is to obtain a hull form with the minimum total resistance (ZHANG Bao-ji, 2008). It is a fact that the wider the hull the greater resistance the ship will face and consequently the more fuel will burn.

There are three available options to optimize vessels form (ABS, 2013). In particular:

- Acceptance of available hull form and propulsion system
- Modifications in the existing hull form.
- Development a new form

The first option requires the least costs. Many of the vessels are optimized in terms of design but not in terms of ballast and service conditions. Also, ships could be designed with hydrodynamic characteristics but probably not to a great extent. The second option allows modifications in specific aspects such as trim and speed combinations or to stern shape. The third option requires higher costs as it allows design to be in line with power efficiency and propeller efficiency plan. This option is applicable in case ships require special characteristics or shipyards do not provide an appropriate design.

As concerns modifications in the existing hull form, a common technique is modifying the bulbous bow (figure 2), where significant savings can be achieved. Based on ship energy efficient measures (ABS, 2013), '*'The properly designed bulbous bow reduces wave-making resistance by producing its own wave system that is out of phase with the bow wave from the hull, creating a canceling effect and overall reduction in wave-making resistance''*

Figure 2, source: Atlantic Bulk Carriers Management Ltd, 2013

In many cases a modified bulbous bow has contribute to decrease fuel consumption up to 5% or even 7% (ABS, 2013). According to Zachariadis Panos, "The Basics of Eco Design'', a vessel of a Greek shipping company with a properly modified bulbous bow burns 2 tons of fuel less which in other words is 7% less of the total fuels or 439,000$ less per annum.

3.3.3 Main engine

Regarding the optimization of the main engine of ships there are various techniques that they are used. Some of them are computer controls and microprocessors which can monitor the fuel injection timing, fuel injection amount and on low-speed diesel engines the exhaust valve timing. The key point that allows electronically controlled engine is the hydraulic system which is a source of power for exhaust valve operations and fuel injections pumps. The efficiency gained from electronically controlled low-speed diesel engines is between 2% to 2.5%. Also, the electronic controlled engines are in line with MARPOL Annex VI Tier II NOx requirements. It is also achievable with electronic control to mitigate NOx at power levels required for Tier II compliance while achieving lower overall SFOC.

Moreover, the engine market provides more contemporary systems for monitoring cylinder lubrications systems. In particular, the last few years the lubrication of diesel engines can be controlled electronically by automated cylinder lubrication systems. More specifically, the time and the amount of the oil injections are precise as it is electronically organized. The adoption of these systems mitigates oil consumption by 25% to 30%. According to the size of the engine as well as the operation hours and cylinder costs the cost savings per year are close to $100,000. Additionally, the adoption of such a system reduces particulate matters released from ship engines. Furthermore, in electronically controlled engines, specific exhaust gas and turbocharger equipment can be installed. This results to SFOC decrease which is significant for ships that function in slow speeds for less fuel consumption. The SFOC decrease, due to special turbocharging optimization systems, is about 3% at low to medium load. However, actions which are in line with SFOC reduction at the same time increase NOx emissions.
The options for optimizing turbocharging can be namely presented below (ABS 2013):

1. Exhaust Gas Bypass (EGB)
2. Variable Turbocharger Area (VTA for MAN) and Variable Turbine
3. Geometry (VTG)
4. Turbocharger Cut-Out (for engines with multiple T/C)
5. Engine Control Tuning (ECT)

Finally, a device which is the most profitable is the waste heat recovery system (WHRS). A WHRS is a device installed in the main engine of ships in order to recover the energy produced and cannot be exploited. Without this device the energy would be lost as heat into the atmosphere. In a typical engine, the waste heat goes into exhaust gases and then released to the air. Therefore, by adding a WHRS in the engine, energy can be recovered by two ways. Firstly, according to Fathomshipping (2013) ‘*’the gases*

leaving the engine pass through a turbocharger which uses the energy of the gas to spin a turbine that not only produces electricity but also forms part of an air compressor. This compressor increases the mass of air that flows into the engine, enabling large quantities of fuel to be burnt more efficiently''. Secondly, the energy of the exhaust gas can be used to generate steam which then can be used to meet the demands on board for heat (gcaptain, 2013). It is worth mentioning that economy of scale applies here and the bigger the main engine output, the more energy produced and as consequently the more energy can be recovered (ABB, 2013).
There are three options for installing a WHRS (gcaptain, 2013):

1. (STG) Steam Turbine Generator
2. (PTG) Power Turbine Generator
3. (ST-PT) Steam Turbine-Power Turbine generator

The PTG, which is the cheapest system among the three, uses a turbine installed in the exhaust gas bypass and produces electricity. It is said that this system is able to recover up to 3-5% of the energy content of the fuel.

The STG is used for onboard heating and uses part of the gas in order to generate steam for a gas-fired boiler. It is more efficient than the PTG system and is able to recover 5-8% of the energy content of the fuel.

The ST-PT system is a combination of the previous two systems. It produces both electricity and steam and it is mainly for ships with high electricity demand such as containerships. This system is able to recover 8-11% of the energy content of the fuel.

The financial benefits of installing a WHRS can be significant, as according to a WHRS manufacturer, 36m$ reduction in fuel costs can be achieved if a ship-owner keeps the vessel for at least 20 years (gcaptain, 2013). Moreover, although the cost of each system is not known, it's a fact that the initial cost of the WHRS will eventually be covered by the fuel savings throughout the life of the vessel (ABB, 2013).

To conclude, it is important the various devises to be compatible between each other and to select the appropriate devices for certain ship types.

3.3.4 Other ESD examples

Air lubrication system

The air lubrication system gains up to 10% fuel propulsion efficiency and theoretically it is applicable in all ship types. However, its technology is still under research. In addition their cost varies between medium to large. The aim of this system is to eliminate the propulsion energy required and to make air and used wherever water interacts with the vessel. There are two types of this system: air cavity systems and micro bubbles.

- The air cavity systems include the production of a thin air layer on the bottom of the vessel which can effectively reduce friction resistance. However, as the ship speed increases the stability of the air cavity systems is conserved more difficult. As a result, in case stability cracks the vessel resistance is significantly increased.

- The system of micro-bubbles is still under research. This system aims in producing thin air layer over vessel sides. The difference with air lubrication system is that micro-bubble systems do not require ensures of stability and also the energy requirements are less. However, it seems that the production of adequate number of micro-bubbles and maintaining them to ship sides is extremely hard. As a result, the frictional resistance could become more difficult to be reduced.

Exhaust Gas Cleaning System

This system is of great significance because any ship which operates within an emission control area (Marpol annex VI) is obliged to burn low-sulphur fuel or to utilize an EGCS. However, it is not only the regulations that ship owners should consider but also that by utilizing their ship's EGCS they achieve significant fuel savings. Hence, the fuel cost savings could be calculated by the equation below :(Kevin J. Reynolds, 2011)

$$\begin{aligned} &Fuel\ Cost\ Savings \\ &\qquad = (ECA\ fuel\ consumption * Distillate\ Cost\ differential) \\ &\qquad - (EGCS\ capital\ and\ Operating\ Expenses) \end{aligned}$$

Whereas, Distillate cost differential is the cost difference between distillate and residual fuel.

An exhaust gas cleaning system is actually scrubbing technologies which can be separated to wet or dry systems.
The wet system uses water (fresh or seawater) to remove SOx and PM from the exhaust gas. It can be categorized as open loop, close loop or hybrid. The difference among the three systems is the type of water they use as scrubbing agent. The open loop uses seawater, the close loop uses fresh water while the hybrid system uses both fresh and seawater. The advantage of the open loop system is that it takes advantage of the alkalinity of the seawater and it doesn't use any chemicals as the close loop system in order to affect the scrubbing process. However, the close loop system can operate in all regions without considering the alkalinity and the temperature of the seawater. Finally, the hybrid system combines the advantages of the open and close loop system. While the ship is in the port fresh water can be used to avoid issues from low quality water and when the ship is in the sea, the system can use seawater to conserve chemicals.

On the other hand, according to Kevin J. Reynolds, 2011, the dry system does not rely on water but on dry bulk reactants for cleaning the exhaust gas, such as calcium hydroxide, in spherical pellets form which are stored on-board. While adding the pellets to the exhaust gas, they react chemically with the SOx and it is produced gypsum and water. Then, the water is discharged in sea while the gypsum is captured for subsequent offloading. The only disadvantage of this system is that extra space is needed on the vessel to storage the spherical pellets.

Regarding the economic aspects of the scrubbing technologies, it is important to mention that the biggest the engine the more expensive the cleaning system is. An estimation of the scrubber costs is presented below: (Table 1)

Title: ''Scrubber costs''

Scrubbers (By engine size)	Open Loop	Closed Loop	Hybrid	Dry
36MW	3.1m$	3.85m$	3.6m$	6.05m$
16MW	2.9m$	3.6m$	3.12m$	3.2m$
12MW	2m$	2,5m$	2.22m$	1.9m$
10MW	1.8m$	2.15m$	1.92m$	1.6m$
3MW	1.3m$	1.85m$	1.56m$	1.25m$
1MW	1m$	1.75m$	1.26m$	930.000$

Table 1, source: Kevin J. Reynolds, 2011

To conclude, ship owners should take into consideration that scrubber suppliers use different designs which have different water and power requirements. Therefore, before he makes the selection of a device he should study the engineering details of different providers.

Renewable energy sources

The optimization of renewable energy sources is under global consideration in various sectors. In shipping sector, the attention is focused on wind and solar power. By exploiting wind power up to 30% mitigation of propulsion fuel consumption is achieved. The technology is developing and still adjusting while it seems to be applicable depending on the ship's structure and operational conditions. This method can be established to new slow speed ships or as retrofits in the already existing. Also, this energy source requires medium level of costs, without conservation costs to be defined. Wind power is easily efficiently exploited, although the technology seems to be still developing. However, towing kites (Figure 3) are the only until now accessible technology. The kite speed gain air efficiency as the air increases while computer control is required. A factor that limits the adoption of this system is the small range of wind conditions that are appropriate as well as the uncertainty of kites operation in adverse weather.

Figure 3, source: nauticwebnews, 2011

Apart from towing kites, Flettner Rotors (Figure 4) is a device that exploits wind power. The Flettner Rotors are vertical, cylindrical sails which produce propulsive power to the direction wind hits the rotors, consequently, rotors gain the optimal efficiency. These devises can be used additionally with the towing kites. However, these devises are powered by diesel engine and they can also increase fuel consumption when they are not in use. As a result, it is unknown whether they provide actual efficiency.
The solar power can just insignificant mitigate fuel reduction while its applicability is rare as its technology is still developing. However, solar energy systems are capable of being installed to all types of ships with medium level of costs. It is suggested solar panel to be installed as additional sources of power. The power gained can be used to power lighting or other electrical requirements of the crew's accommodation areas. Finally, it seems that from this type of system, due to its high capital costs, not adequate benefits are gained.

Figure 4, source: uglyships.wordpress.com, August 2010

3.4 LNG as fuel

Liquefied natural gas (LNG) is actually a natural gas which is converted to liquid form in order to be transported and used more easily. It is transported worldwide with the LNG vessels into specially designed tanks. However, LNG is also used as ship fuel as it constitutes an efficient alternative option for reducing pollutants and fuel consumption. In particular, LNG as fuel is capable for reducing SOx emissions significantly since a gas fuel engine in a typical cargo ship emits zero SOx emissions while low sulphur fuel and conventional fuel are responsible for 5 tonnes/year and 48 tonnes/year respectively. Moreover, an engine that burns LNG emits about 25 tonnes/year of NOx which constitutes in total reduction of 90% compared with a conventional engine. It is also interesting to mention that 1 ton of diesel emits 3.2 tons CO_2 while 1 ton of natural gas emits 2.55 tons CO_2. The achieved reduction is 25% but since gas contains higher energy contents the reduction can be 30% compared with oil.

Regarding the prices among bunkers, in July 2012 the LNG delivered US Coast (LNG delivered =Henry Hub+4$/mmBTU) was at the lowest level as it reaches the level of 8 $/mmBTU. The HFO and MDO prices have reached the level of 15$/ mmBTU and 24$/mmBTU respectively (Figure 5).

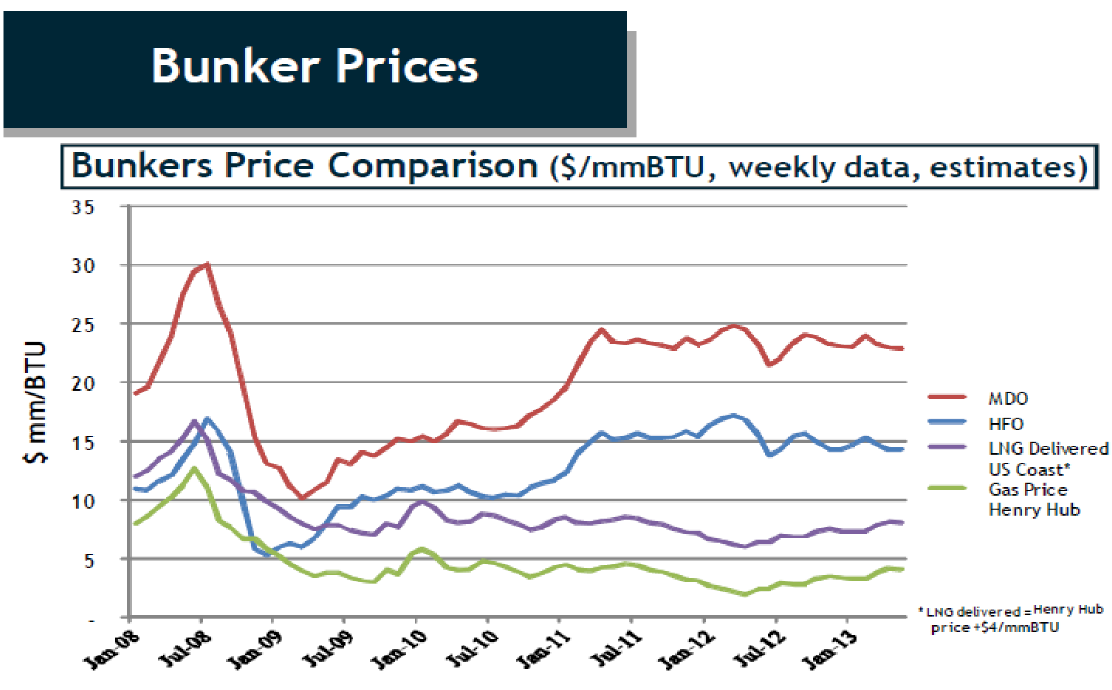

Figure 5, source: Atlantic Bulk Carriers Management Ltd, 2013

It is a fact that the fuel costs hold the biggest share of daily costs in vessels which can be from 60 to 78%. Today, LNG prices are almost 50% cheaper than Gasoil and 30% cheaper than Fuel oil. In particular, the LNG price is a bit more than 10$/mmBTU, the Fuel oil price is close to 15$/mmBTU and the Gasoil price is close to 22-23$mmBTU

(Zolotas Spyridon, 2013). It is said that between 2016 and 2021, the MDO price is expected to be over 1000$/ton, the LNG High price over 800$/ton, LNG Low price over 400$/ton and the HFO over 600$/ton.

A case study for a 50,000 dwt tanker presents the comparison between a dual fuel engine tanker and one with a standard unit.

In terms of new-building prices a tanker with the standard unit could cost 32-34m $, whereas a dual fuel engine tanker could cost 8.5m$ more (Zolotas Spyidon, 2013). In addition, supposing that the vessels would be financed 100% with a 20-year swap plus 3.5% margin, the capital daily cost of a standard unit ship would be 8.000$/day while for a dual fuel vessel would be 10.000$/day. (Figure 6)

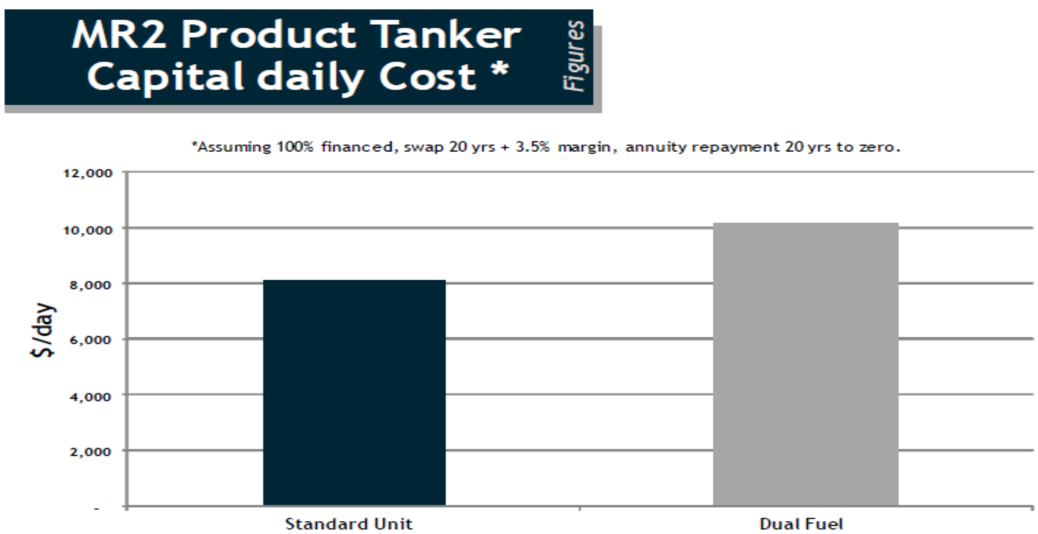

Figure 6, source: Atlantic Bulk Carriers Management Ltd, 2013

Furthermore, it is essential to mention that the installation of the LNG engines in existing ships is not as effective as the application to new vessels. The LNG engines are more applicable to new vessels since they are larger and they require around 1.6 times more volume than the conventional engines. The space required in an existing ship is difficult to be found and thereafter the installation process would also be more expensive.

Regarding the LNG engine total costs, they are influenced by the type of ship and the ship size. An LNG engine is estimated to be 20% more expensive than a conventional engine (Zolotas Spyridon, 2013). In addition, the added cost of investment for LNG propulsion ranges from 800 to 1.200 €/kW, assuming that the installed power will be between 2.000 and 9.000 kW. However, the prices are expected to fall approximately 250 to 400 €/kW.

Last but not least, although the LNG as fuel has many advantages both from ecologic and economic point of view, ship-owners who are willing to build vessels with dual-fuel engines should also consider that there are really few locations to fill their ships (Figure 7). As a result, the main obstacle for the more extensive use of the LNG is the lack of

LNG fuel infrastructure. However, the price advantage of LNG over HFO and over diesel remains consistent and balances the lack of LNG infrastructure.

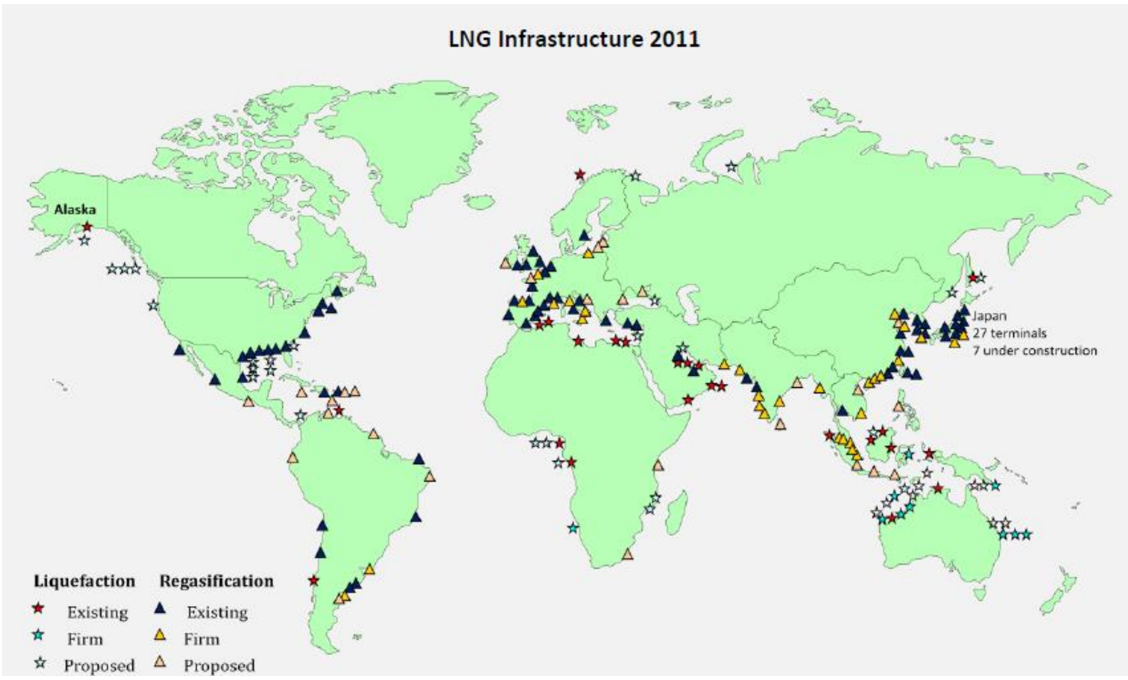

Figure 7, source: James Ashworth, 2012

Chapter 4 Eco-Ships

4.1 Introduction

Nowadays, the environmental regulations and the higher fuel prices demand for technologies that should be installed and to meet the legal requirements. The upcoming challenges in the shipping sector are focusing on cleaner, ''greener'' and more efficient vessels. In the long-term, the environmental regulations in the shipping sector will be stricter. In addition, the customers will become more environmentally conscious and the awareness for more efficient transportation will be widespread. As a result, this will lead the shipping sector to become more efficient and to adopt ''green'' technologies. Until now, many shipping companies have introduced eco-design ships or converted their vessels to eco-design by installing eco technologies. The eco-ships refer to both the senses of ecological and economical ships as an eco-ship should not only be beneficial for the environment but also for the ship-owner. Thus, eco-ships are capable of contributing effectively to shipping sustainability and to efficient transport.

4.2 Eco-design Ships

It is interesting to mention some market examples of vessels which adopted effectively new technologies and consequently improved their performance.
Firstly, such an example of an eco-ship is the 4,200 GT Super Eco-Ship manufactured in ''Niigata Shipbuilding & Repair, Inc''. The new technologies established in the design and construction of the Super Eco-Ship contain the use of an electric propulsion system powered by a highly efficient super marine gas turbine (SMGT), contra-rotating pod propellers, and a low resistance hull form. In order to enhance efficiency while reforming ship operations, a wide range of automated systems are also installed in the Super Eco-Ship. In particular, those systems aim to mitigate the amount of work loads that are necessary in the ship consequently, less crew is necessary. In addition, centralized computer controlling systems and use of electric rather than hydraulic powered systems prevent from oil leakage that can possibly occur. More specifically, the adoption of SMGT offers various benefits. Initially, the NOx emissions are significantly reduced comparing with vessels powered by diesel engines. Also, the gas turbines are smaller and lighter, easy conservative, less noisy and produce less vibration. However, the limitations of installing this system are mainly economically based to higher fuel costs. The SMGT engine of Super Eco-Ship achieved 38% efficiency throughout ship tests and can lead to 90% reduction of NOx emissions, 60% reduction in SOx emissions and 25% decrease in CO_2 emission.

Secondly, the NYK Super Eco Ship 2030 is another example of an eco-design ship (NYK Line／MTI, "NYK Super Eco Ship 2030") (Figure 8). The actions that will take place in this vessel in order to generate efficiency and to mitigate CO_2 emissions are separated to three sections, namely reduction of power, adoption of new technology for power generation and use of renewable power sources. More specifically, the mitigation of power includes:

- reduction of weight
- reduction of frictional and wind resistance

- increase of propulsion and motor efficiency as well as
- Improvement of hull form.

The use of new technology for power generation refers to adoption of fuel cells as well as adoption of alternative fuels (H_2 and LNG).

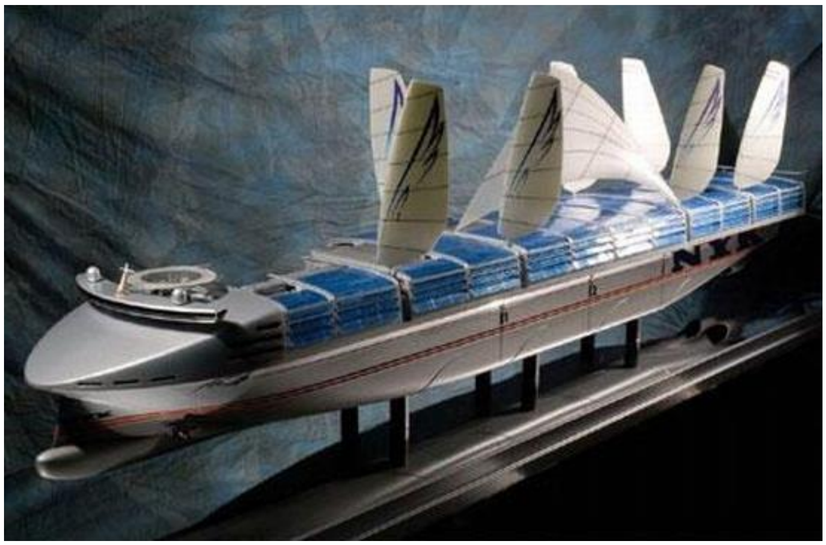

Figure 8, source: worldmaritimenews.com, Feb 2013

Another example of an eco-design ship that could be referred is the ISHIN-III, an iron ore carrier introduced by Japan's Mitsui O.S.K Lines Ltd (Marine Log, Company "Designing Future Eco-ships", May 2010). In this bulk carrier, waste heat recovery system is installed. The waste recovery system improves vessel's propulsion since the system converts heat energy recovered from engines to electricity and consequently, achieves reduction in fuel consumption. Also, in ISHIN-III a combination of turbocharger and electronically controlled engines is installed, in order to reduce CO_2 emissions by 30%. Moreover, low friction ship bottom coating is adopted as well as Propeller Boss Cap Fins for improved and more efficient propeller system. Consequently, the establishment of an integrated plan which includes optimization of hull form, voyage optimization and taking advantage wind and solar power source leads to more than 50% reduction in CO_2 emissions comparing with a carrier without any modifications.

Continuing, the Stena Airmax, a 15-meter tanker launched by Stena Teknik in Sweden in which air cushion technology has been installed, reducing friction and fuel consumption (Marine Log, "Designing Future Eco-ships" May 2010). Stena Airmax has been also manufactured with a flat bulbous bow and the overall expected savings are 20% to 30% which however have not been yet verified.

Moreover, the Malaysian-headquartered tanker operator AET in 2012 has scheduled for delivery four Suezmax, environmentally friendly vessels in order to achieve more fuel efficiency and fewer emissions (Motorship, 2012).In particular, vessel's hull form was optimized for less resistance and the main engines were de-rated, which means that larger engines were installed and used in lower MCR. Also, the vessels were supplied with saver fins, high efficiency propeller as well as a rudder bulb, which all together generate more fuel efficiency. The maximum capacity of the AET eco-friendly vessels was close to 157,000 dwt. The adoption of innovative technology in the vessels results to environmentally benefits and more fuel efficiency which leads to win-win corporations between customers, ship-owners and environment.

Regarding eco-design ships, the ship of the year 2012 has been chosen by Japan Society of Naval Architects and Ocean Engineers (JASNAOE) to be the NYK-owned coal carrier, Soyo (Safety4sea, 2013). An air lubrication system has been installed which improves the propulsion efficiency by almost 10%. This new air lubrication system was jointly developed by NYK, ''Oshima Shipbuilding Co. Ltd'', and the ''Monohakobi Technology Institute'', in cooperation with the National Maritime Research Institute. Moreover, this air-lubrication system achieves less frictional resistance as it leads the combustion air to vessel's bottom.

Last but not least, the aim of the Ecoliner concept is to use as less fossil oils, as possible, to eliminate the overall ship emissions while the payback horizon to be close to 20 years (Figure 9). Additionally, the Ecoliner concept is suitable for tankers, bulk carriers or heavy cargo ships. The vessels that would adopt the Ecoliner concept are designed to operate in 12 knots but are able to reach 18 knots under sail depending on wind speed and angle. Furthermore, an algorithm can be used to utilize the route, the fuel consumption as well as the speed by controlling an electric motor. The required power when motor-sailing is less and the way of sailing becomes significant efficient. This is explained from the sails better performance while ship develops higher speed and consequently the required power is less.
The Ecoliner concept is based on developing the following issues:

- Hull and appendages
- Rig development
- Sailing rig
- Operation
- Performance evaluation

Figure 9, source: Dykstra, January 2013

4.3 Eco-converted Ships

When ship-owners are deciding to adopt new technologies it is important not only to take in account emission reductions and mitigation of fuel consumption but also the cost of the adopted technology. In addition, fuel prices play an important role to the current market conditions; therefore ship-owners are under concern not only about the time of investing but also about the choice of the adopting technology. The market is also more convinced by the results of the eco ships and is increasingly moving towards the ‘’greener’’ path.

It is worth mentioning at this stage some examples of eco-converted ships which have been introduced in the market the last two years. Firstly, a containership 8,600 TEU, Hyundai Brave vessels by HMM in corporation with DNV Norway’s classification and DSEC (Worldmaritimenews, April 2013). In order to reduce fuel consumption, they modified the bulbous bow with a bow in dolphin shape 1.5m shorter (figure 10), resulting in 3% fuel savings which is translated to 1.040 ton of fuel and 0.6 million USD.

Figure 10, source: Jane Nguyen, 2013

Secondly, according to a shipping company in Greece (Danaos, 2013), they are about to introduce an eco-converted containership of 8,000 TEU. The total investment cost will be 2m USD and the new design specifications are:

- Engine de-rating & new propeller-6%
- Semi-circular duct-2%
- Hull optimization(Bow)-4%

Therefore, the propulsion efficiency will be 12% more than the existing design which means that the total fuel savings are almost 3, 5 tons per year.

Chapter 5 Economic and Cost Benefit Analysis

5.1 Introduction

In this chapter, an economic analysis regarding non-eco, eco-design and eco-converted bulk carriers is included. It starts with a literature review concerning bulk carriers' ships. In the next subchapter, we compare non-eco and eco-design total costs for various ships sizes for a specific shipping route. The chapter is completed with a cost benefit analysis between eco-converted and eco-design ships

5.2 Bulk Carriers, a review

Before the Econometric and Cost Benefit Analysis it is essential to present a review of the ships which are being analyzed.

Some generic information about bulk carriers are provided below with potential problems that they face and their proposed solutions. Initially, bulk carriers are ships manufactured for cost-efficient, major carry of dry bulk commodities such as iron, coals, alumina and ore concentrates. Originally, bulk carrier ships aim was the transportation of raw materials, where now bulk carriers are established in deep sea trading.

Another design of bulk carriers is the combination carrier OBO (Ore, Bulk, Oil). In particular, the ore carrier which almost completely carries high density cargo such as iron ore with a density of up to 3t/cub.m on long-distance hauls. Comparing general bulk carriers, the ore carrier is manufactured for homogeneous cargo transportation only. These ships aim to reduce the transportation costs through economies of scale. Also, the Oil/Ore carriers were vessels where the one leg was carrying ore and the other oil. Later, dry specialized bulk carriers were introduced to the market. These vessels were appropriate for more enhanced special trades or high-value commodities.

Other types are the open hatch vessels in which the cargo loaded do not face any obstacle due to overhangs. These vessels carry usually forest products such as paper rolls and wood pulps. Moreover, the mini bulk carriers are vessels with only one cargo hold with a box shape hold structure. The semi-open hatch bulk carriers range between 28,000 and 45,000 dwt and seem to be significantly operational flexible. The wood chip carriers are developed in order to transport light density wood chips which require large hold volumes. These vessels range between 40,000 and 50,000 dwt. Their introduction to the market is exclusively arranged by Japanese operators.

Nowadays, in terms of structural design developments, there are huge changes. In particular, the new built bulk carriers contain high proportions of high tensile steel. Also, the deadweight has increased due to the less steel weight the structure contains. It is also essential to mention that the decade of nineties taught to the shipping industry when bulk carriers face severe hull failure at sea; the probability of sinking is higher than in most of the other ship types. In addition as the link between hull failures and the aging of the bulk carrier was noticeable, made the International Maritime Organisation (IMO) and the International Association of Classification Societies (IACS) to decide to collaborate for structuring short and long term policies.

Moreover, in the dry bulk cargo market, there is significant difference between the importing and exporting areas. As a general bulk carrier functions in a cargo and in ballast leg approach and as the ballast leg and cargo leg proportion is almost 50-50,

ship-owners put their vessels into ships. This method utilises the potential fleet by distributing the candidate which might be conveniently close to a loading.
It is a fact that there is potential difference between loading terminal performance and the design of bulk carriers. Following, there are some solutions that could be adopted to improve the situation. It seems that up to 52 m in length and interconnected individual WB tanks, do not always separate tank level controlling and valve control from a central WB console. Also, some design practices for the ballast system may significantly contribute to early corrosion, cavitation or valve failures. It is proposed about loading to be manual so as to be clearly representative which capacity can safely be in process throughout ballasting and de-ballasting procedures respectively. In addition, the loading sequence conditions organized by the designer are not constantly linked to the loading rate and pump capacity available for de-ballasting. Moreover, it seems that the loading and de-ballasting rates are not constantly time-synchronised. Finally, some certain design features are less developed ballast pump capacities, in particular for the Panamax and Handymax segments, which may not be capable to manage with high loading rates.
Last but not least, it is interesting to discuss modifications to standard yard specifications for bulk carriers, focusing on strengthen hold cleaning. This could generate benefits throughout the service life of the vessel at a reasonable extra cost. With clean equipment available on board, especially with a cleaning friendly designed hold configuration, many problems and obstacles the crew faces can be eliminated, which may engage extra cost in the case that a vessel is rejected permission to load the next cargo. Initially, ship designers should guarantee access of cargo to remote areas by structural organization of the vessel. Moreover, it is difficult to access for monitoring, conservation and cleaning the overhead structures in way of the cross. Also, the use of inverted angles is not appropriate due to the fact that dust from dry cargo operations will stick. It is suggested closed box structures to be used for bulk vessels and at the same time they should be structured with access from above.

5.3 Economic analysis

5.3.1. Introduction

The aim of this subchapter is to present a comparative total cost analysis between non-eco and eco-design bulk carrier ships. For a specific trip, we calculate the total costs for a non-eco and an eco-design bulk carrier. Further, we conduct a statistical analysis for the economic benefit which occurs from the use of eco-design ships.

5.3.2 Data collection

As far as fuel prices, “platts” database has been used. The rest of the data were taken from Hellenic Shipping Companies.

5.3.3 Methodology

First of all, we summarize the total cost per day of a non eco and eco bulk carrier (Handymax, Panamax and Capesize). Note, that the only difference between eco and non-eco is the daily fuel consumption, while the differences in lubricants are negligible. Then, we calculate the daily costs of them for our trip taking monthly fuel prices for the period January 2011 up to August 2013. After that a statistical analysis for the occurred benefit is conducted. Further, we should note that:

- For calculations, we consider total days except fuel consumption since fuel consumption at ports is negligible thus could be fully ignored.
- For calculations, we round 66.02 days to 60 since we have monthly data for fuel consumption. This difference does not make significant difference to the results.
- The following formulas are being used:

  Benefit ($/trip) = Total cost of non-eco ship - Total cost of an eco-design ship
  Benefit (%) = 1- (Total cost of an eco-design ship / Total cost of non-eco ship)

5.3.4 Results & Conclusions

Below, we present the cost analysis for the bulk carriers.

Handymax Bulker costs ($/day)	
Crew Costs	$2,572.00
Stores	$794.00
Repairs & maintenance	$899.00
Insurance	$578.00
Administration	$994.00

Table 2, source: Hellenic Shipping Companies

Where:	
Crew Cost:	Crew wages, provisions, Crew other
Stores:	Lubricating oils, Stores others
Insurance:	P&I insurance, marine insurance
Administration:	Management Fees, Sundry expenses
Fuel Cost:	Assuming cruising speed 14knots/mile

Handymax Consumption (tons/day)	
Non ECO-ship	20.00
ECO Design (slow rotating propeller, wake equalizing duct, larger engine)	16.00

Table 3, source: Hellenic Shipping Companies

Panamax Bulker costs ($/day)	
Crew Costs	$3,103.00
Stores	$892.00
Repairs & maintenance	$862.00
Insurance	$644.00
Administration	$1,105.00

Table 4, source: Hellenic Shipping Companies

Panamax Consumption (tons/day)	
Non ECO-ship	37.80
ECO Design (modified bow, larger propeller and larger engine)	26.70

Table 5, source: Hellenic Shipping Companies

Capesize Bulker costs ($/day)	
Crew Costs	$3,286.00
Stores	$1,181.00
Repairs & maintenance	$1,024.00
Insurance	$790.00
Administration	$1,477.00

Table 6, source: Hellenic Shipping Companies

Capesize Consumption (tons/day)	
Non ECO-ship	58.00
ECO Design (larger engine, hull optimization, larger propeller, ducts)	50.40

Table 7, source: Hellenic Shipping Companies

The following table describes the shipping route:

Shipping route					
Load Port	***Discharge Port***	***Total Miles***	***Total Days***	***In Port***	***Days of operation***
Fujairah	Rotterdam	6032	19.33	4	15.33
Rotterdam	Lagos	4141	13.27	4	9.27
Lagos	Rotterdam	4141	13.27	0	13.27
Rotterdam	New York	3282	10.52	4	6.52
New York	Huston	1900	6.09	2	4.09
Huston	Aruba	1774	5.69	2	3.69
Aruba	Huston	1774	5.69	4	1.69
Huston	Amsterdam	5043	16.16	4	12.16
Total		28087	90.02	24	66.02

Table 8, source: Bachero Cost Research

In Appendix 2 all the calculations are being presented. Here, the thesis focuses only in the results analysis.

Statistics for the benefit ($/trip)			
	Handymax	***Panamax***	***Capesize***
Average	$163,655.33	$454,143.53	$310,945.12
Standard Deviation	$11,059.34	$30,689.67	$21,012.75
Max	$186,968.64	$518,837.98	$355,240.42
Min	$136,463.34	$378,685.77	$259,280.35
Range	$50,505.30	$140,152.21	$95,960.07

Table 9, source: own calculations.

Based on fuel prices of that period we find that the average benefit from the use of an eco-design Handymax bulk carrier comparing to a non-eco for that trip is $163,655.33

per trip. The max benefit spotted was $186,968.64 per trip where the minimum was $136,463.34 thus the range of the benefit is $50,505.30. Standard deviation is $11,059.34.
Regarding to Panamax bulk carrier, the average benefit from the use of an eco-design Panamax bulk carrier comparing to a non-eco for that trip is $454,143.53per trip. The max benefit spotted was $518,837.98 per trip where the minimum was $378,685.77 thus the range of the benefit is $140,152.21. Standard deviation is $30,689.67.

Last but not least, the average benefit from the use of an eco-design Capesize bulk carrier comparing to a non-eco for that trip is $310,945.12trip. The max benefit spotted was $355,240.42 per trip where the minimum was $259,280.35 thus the range of the benefit is $95,960.07. Standard deviation is $21,012.75

Turning to benefit (%) results:

Statistics for the benefit (%)			
	Handymax	***Panamax***	***Capesize***
Average	8.75%	17.47%	9.07%
Standard Deviation	0.34%	0.49%	0.19%
Max	9.42%	18.41%	9.44%
Min	7.87%	16.18%	8.56%
Range	1.54%	2.23%	0.88%

Table 10, source: own calculations

Using an eco-design Handymax instead of a non-eco for that period the total cost would be decreased by 8.75% on average. The max percentage spotted is 9.42% while the minimum was 7.87% and as a result the benefit (%) range is 1.54%. Standard deviation is 0.34% thus it is not seem to have significant volatility.

Using an eco-design Panamax instead of a non-eco for that period the total cost would be decreased by 17.47% on average. The max percentage spotted is 18.41% while the minimum was 16.18% and as a result the benefit (%) range is 2.23%. Standard deviation is 0.49% thus it is not seem to have significant volatility.

Using an eco-design Capesize instead of a non-eco for that period the total cost would be decreased by 9.07% on average. The max percentage spotted is 9.44% while the minimum was 8.56% and as a result the benefit (%) range is 0.08%. Standard deviation is 0.19% thus it is not seem to have significant volatility.
To sum up, the use of eco-design ships these years could reduce the total cost of the trip by 8.75% minimum and by 17.47% maximum on average. Additionally, the benefit seems to be a stable variable.

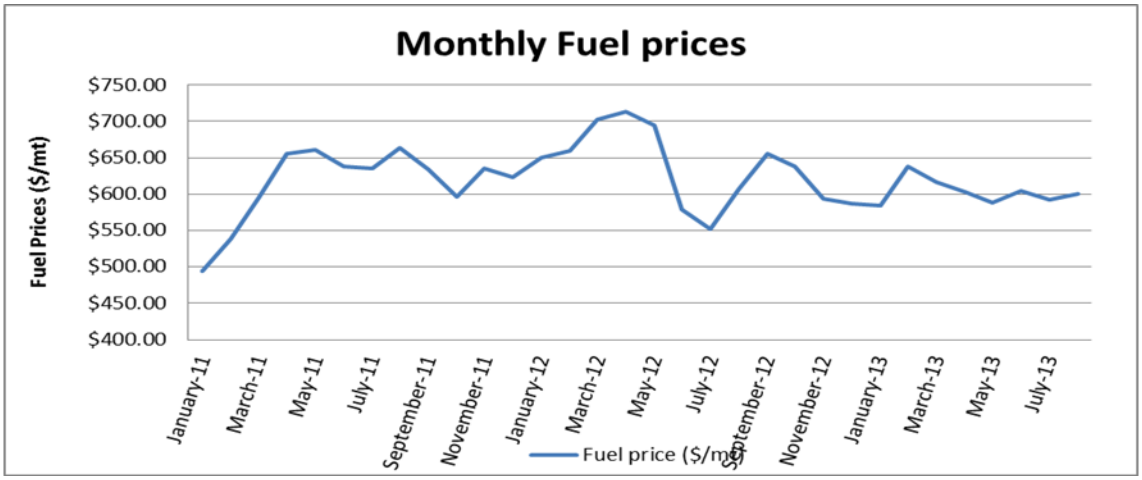

Figure 11: Monthly Fuel prices (January 2011-August 2013), source: “platts” database

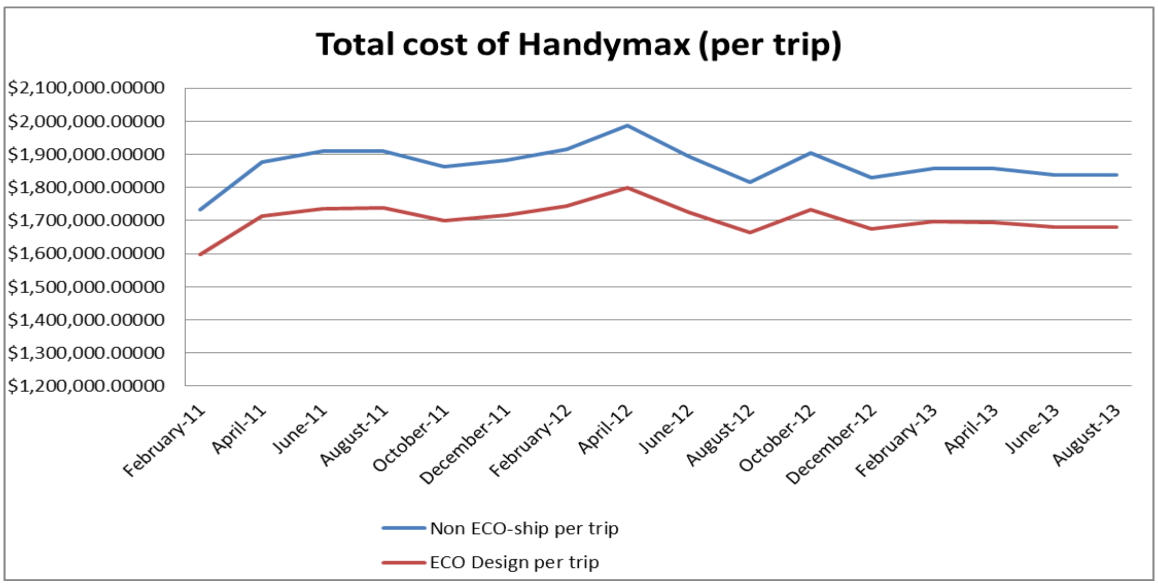

Figure 12: Total Cost of Handymax, source: own calculations

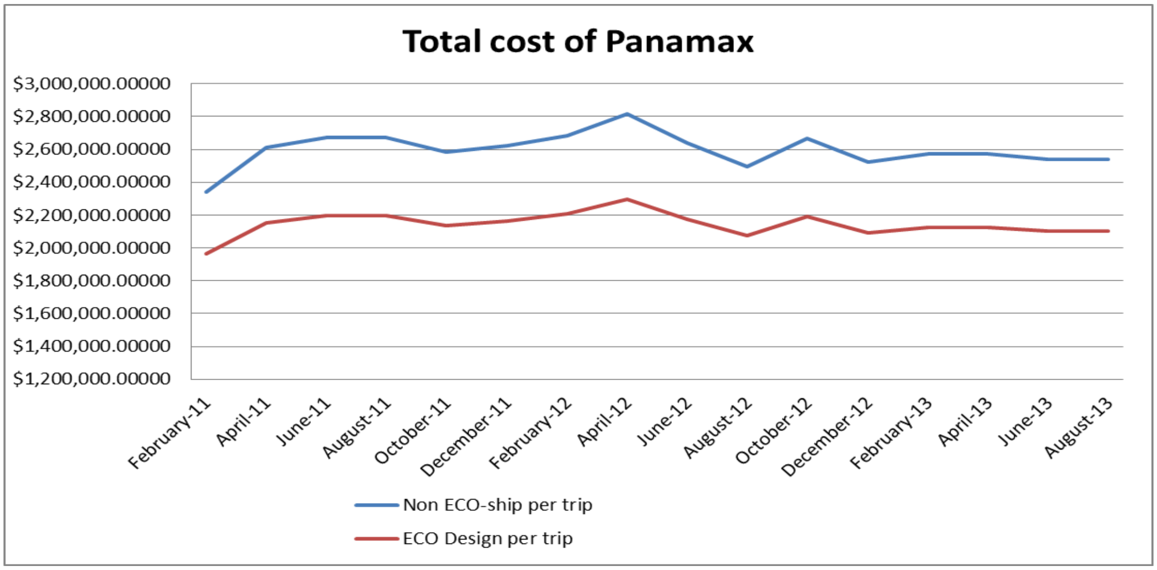

Figure 13: Total Cost of Panamax, source: own calculations

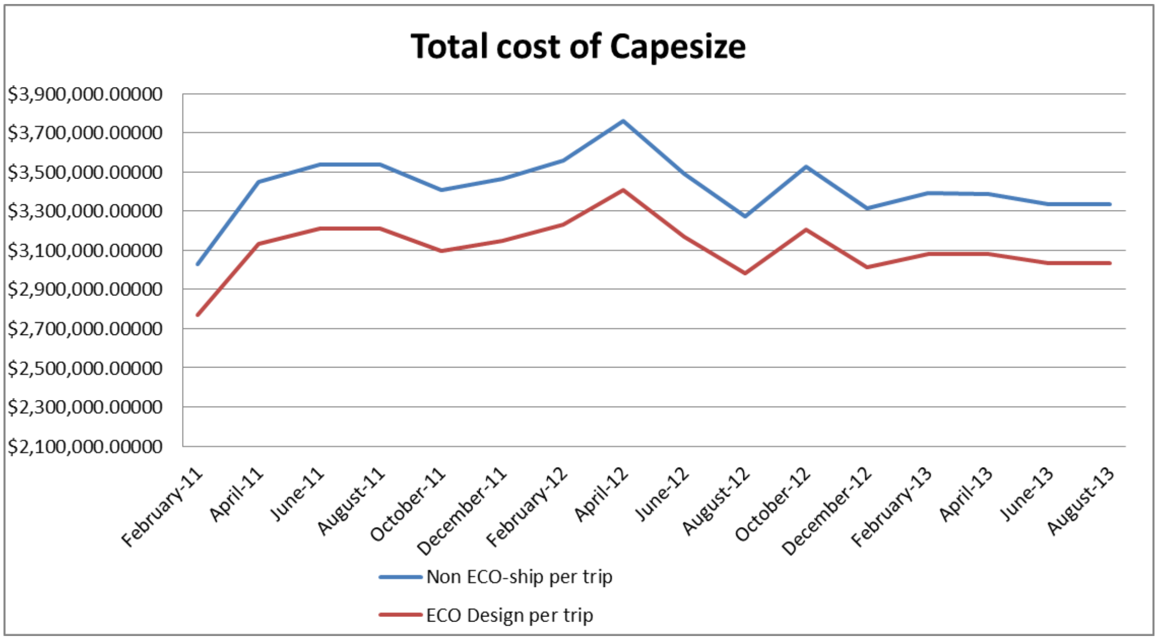

Figure 14: Total Cost of Capesize source: own calculations

Furthermore, the same analysis is conducted but based on different assumption; concerning fuel prices. More specifically, we assume that the average fuel is price for the trip is going to be changed in a range of -40% and 40% from current level (August 2013 fuel price=600). Then, for each 1% percent of change we calculate the total cost of a non eco-design and an eco-design ship and the occurred benefit from the use of an eco-design ship.
In the Appendix II all the calculations are being presented. At that point thesis is focused only in the results.

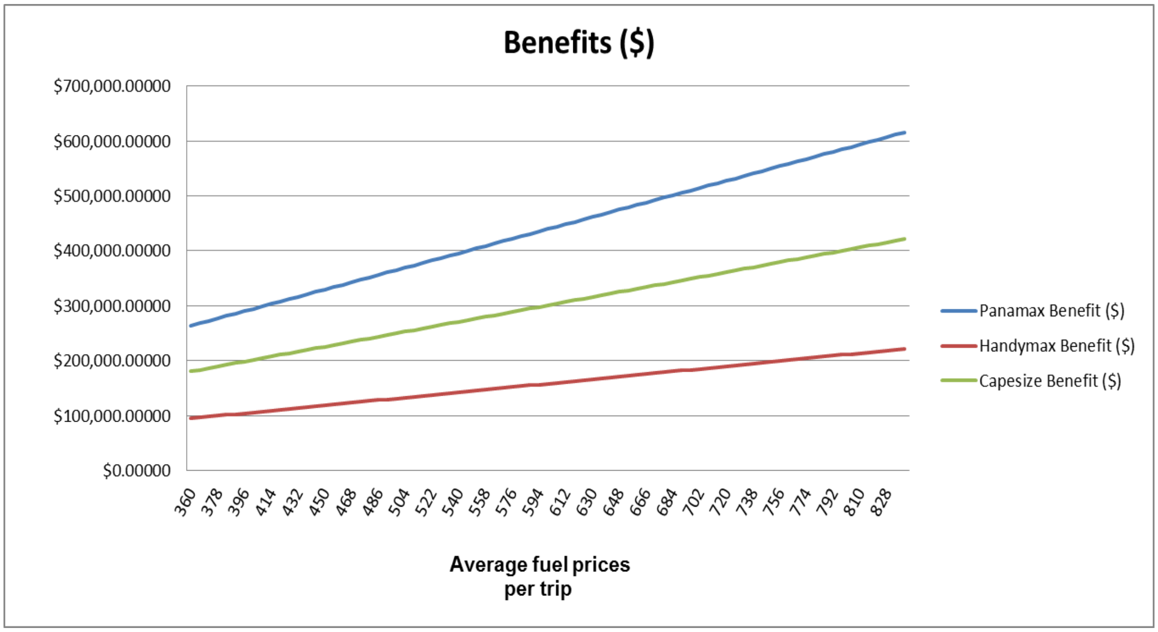

Figure 15: Benefits evolution for different levels of fuel prices, source: own calculations

Statistics for the benefit ($)			
	Handymax	***Panamax***	***Capesize***
Average	$158,448.00	$439,693.20	$301,051.20
Standard Deviation	$37277.40	$103444.78	$70827.05
Max	$221,827.20	$615,570.48	$421,471.68
Min	$95,068.80	$263,815.92	$180,630.72
Range	$126,758.40	$351,754.56	$240,840.96

Table 11, source: own calculations

Based on that assumption for fuel prices we find that the average benefit from the use of an eco Handymax bulk carrier comparing to a non-eco for that trip is $158,448.00per trip. The max benefit spotted was $221,827.20 per trip where the minimum was $95,068.80thus the range of the benefit is $126,758.40. Standard deviation is $37,277.40.

Regarding to Panamax bulk carrier, the average benefit from the use of an eco Panamax bulk carrier comparing to a non-eco for that trip is $439,693.20per trip. The max benefit spotted was $615,570.48 per trip where the minimum was $263,815.92 thus the range of the benefit is $351,754.56. Standard deviation is $103,444.78.

Last but not least, the average benefit from the use of an eco Capesize bulk carrier comparing to a non-eco for that trip is $301,051.20 per trip. The max benefit spotted was $421,471.68per trip where the minimum was $180,630.72 thus the range of the benefit is $240,840.96. Standard deviation is $70,827.05

Turning to benefit (%) results:

Statistics for the benefit (%)			
	Handymax	***Panamax***	***Capesize***
Average	12%	21%	10.6%
Standard Deviation	1.18%	1.42%	0.51%
Max	13.57%	23%	11.26%
Min	9.50%	18.53%	9.49%
Range	4.07%	4.95%	1.78%

Table 12, source: own calculations

Using an eco-Handymax instead of a non-eco the total cost would be decreased by 12% on average. The max percentage spotted is 13.57% while the minimum was 9.50% and as a result the benefit (%) range is 4.07%. Standard deviation is 1.18% thus it is not seem to have significant volatility.

Using an eco-Panamax instead of a non-eco the total cost would be decreased by 21% on average. The max percentage spotted is 23% while the minimum was 18.53% and as a result the benefit (%) range is 4.95%. Standard deviation is 1.42% thus it is not seem to have significant volatility.

Using an eco-Capesize instead of a non-eco the total cost would be decreased by 10.6% on average. The max percentage spotted is 11.26% while the minimum was 9.49% and as a result the benefit (%) range is 1.78%. Standard deviation is 0.51% thus it is not seem to have significant volatility

To sum up, for that range of fuel price the use of eco ship that years could reduce the total cost of the trip by 10.6% minimum and by 21% maximum on average. Moreover the volatility of the benefit remains rather low**.**

5.4 Cost benefit analysis

5.4.1 Introduction

At that point, the study will try to enlighten the economic aspects of the following question from the ship-owner point of view: "Which of the following two options is more profitable: to convert a bulk carrier to an eco-design or to replace it with an eco-design new-building bulk carrier?"

5.4.2 Data collection

To answer, we collect the following dataset:

- Sale prices for panamax bulk carriers from years 2011-2013. Source for that data was a well-known ship-broking company in Greece.
- Average today buy price for eco-design panamax bulk carriers. Source for that variable was various ship-broking companies in Greece. Note that, the dwt factor of the vessels in the price is considered.
- As far as the average building years of an eco-design panamax bulk carrier, is concerned 4 years which is the most usual time period given from shipyards.
- Turning to r we use the current interest rate of the 3-months US treasury bills. We assume same interest rate for the last 3 years volatility of that rate the last years tends to zero.

Regarding, the conversion cost of an existing bulk to an eco-form we take into account the factors:

- Energy saving devices
- Propeller upgrades
- Silicon paints

Note that the costs of the above 3 factors depends on the large variety of them in the market and consequently we calculate the average cost.

5.4.3 Methodology

Thesis is going to follow the below methodology for the calculations since revenues and costs for eco-ships and eco-converted are similar:

- T=0=August 2013. As a result previous sell prices will be transformed to current values employing the Future Value formula:

$$Current\ \ Sale\, Value = Sale\, Price * \left(1 + r * \left(\frac{m}{12}\right)\right) * (1 + r)^N$$

where:

m = months up to next August from sell month
r= interest rate of the 3-months US treasury bills
N =Remaining years from 1st August after the sell

- As for the price of a new eco-design we assume that shipyard will be paid 20% in the beginning and 80% in the end of the building period. As a result, current value of a new eco-ship is given by the formula:

$$Curent\ Value\ of\ a\ new\ eco\ bulk: 0.2 * price + \frac{0.8 * Ship\ Price}{(1+r)^4}$$

- After that we subtract price of new eco-ships from sale prices. The result is the cost for a ship-owner to sell an old bulk carrier and to buy a new eco bulk.
- Then we calculate the average cost (C1)
- Question is answered as soon as we compare the conversion cost with C1.
- If C1>conversion cost then eco-conversion is cheaper than selling an existing bulk and buying a new eco

5.4.4 Results

Cost Summary for eco-conversion		
Eco-converted Methods	Range	Average/Value
Energy saving devices	$150,000-$350,000	$ 250,000.00
Upgrades propeller	$1,000,000-$1,500,000	$ 1,250,000.00
Silicon paints	$250,000	$ 250,000.00
Total Cost for conversion		$ 1,750,000.00
C1		$ 15,684,176.29
Result	Eco conversion is more profitable	

Table 13, 'Final results', source: own calculations

In Appendix 3 full data and calculations are provided.

Chapter 6 Concluding Remarks

6.1 Conclusions

Over the years, conventions and regulations have tried to make shipping ''greener'' but still, there are significant problems that need a solution. It is not only that the environmental policies are not in effect but it should be also in the consideration of the ship-owners to adjust their ships with new technologies in order to emit less and contribute to the sustainable and green shipping and as a consequence they also benefit from the economic point of view.

The study analyses the meaning of an eco-design form and presents various ways with which a ship-owner can convert an existing non-profitable ship to an efficient eco-design. Some of the mechanisms are still developing but there are existing devices which can make ships much more efficient, such hull optimization and propulsion efficiency technics.

To sum up the conclusions, the use of an eco-design ship could reduce the cost of the trip by 8,75% minimum and up to 21% maximum depending on our assumptions for fuel prices. Moreover, the low volatility of the benefit should be stresses as an important evidence of economic analysis. Turning to cost-benefit analysis results, under current conditions of the market is more profitable from the ship-owner point of view to convert a non-eco Panamax bulk carrier to an eco-form rather than to sell it and buy a new eco-design Panamax bulk carrier.

6.2 Recommendations

The presented literature review along with the econometric and cost-benefit analysis provides hard evidence for the following recommendations:

1. Other sizes of bulk carriers as well as other types of vessels are recommended to be examined. That examination is expected to enhance the arguments and the conclusions of this thesis statement.
2. Research community should keep an eye on the conclusions of the thesis since eco-design ships were launched in market just 2 years ago and as a result many facts are probably going to change a lot in the near future. For that purpose, an annual review of the thesis is recommended.
3. During the reading of the literature and from the author's professional experience was noticed that green shipping regulations are not being implemented completely. For that purpose, a study regarding implementations of green shipping regulations is recommended to be made.
4. Further research concerning eco-converted ships is recommended since it was observed a rather small literature

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Appendices

Appendix 1

MARPOL annexes:

Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983):
Covers prevention of pollution by oil from operational measures as well as from accidental discharges; the 1992 amendments to Annex I made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls, which was subsequently revised in 2001 and 2003.
Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983)
Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk; some 250 substances were evaluated and included in the list appended to the Convention; the discharge of their residues is allowed only to reception facilities until certain concentrations and conditions (which vary with the category of substances) are complied with. In any case, no discharge of residues containing noxious substances is permitted within 12 miles of the nearest land.
Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)
Contains general requirements for the issuing of detailed standards on packing, marking, labeling, documentation, stowage, quantity limitations, exceptions and notifications. For the purpose of this Annex, “harmful substances” are those substances which are identified as marine pollutants in the International Maritime Dangerous Goods Code (IMDG Code) or which meet the criteria in the Appendix of Annex III.
Annex IV Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003)
Contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; sewage which is not comminuted or disinfected has to be discharged at a distance of more than 12 nautical miles from the nearest land. In July 2011, IMO adopted the most recent amendments to MARPOL Annex IV which are expected to enter into force on 1 January 2013. The amendments introduce the Baltic Sea as a special area under Annex IV and add new discharge requirements for passenger ships while in a special area.

Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)
Deals with different types of garbage and specifies the distances from land and the manner in which they may be disposed of; the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics. In July 2011, IMO adopted extensive amendments to Annex V which are expected to enter into force on 1 January 2013. The revised Annex V prohibits the discharge of all garbage into the sea, except as provided otherwise, under specific circumstances.
Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)
Sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances; designated emission control areas set more stringent standards for SOx, NOx and particulate matter. In 2011, after extensive work and debate, IMO adopted ground breaking mandatory technical and operational energy efficiency measures which will significantly reduce the amount of greenhouse gas emissions from ships; these measures were included in Annex VI and are expected to enter into force on 1 January 2013.

Table 14: Source: IMO

Appendix 2

Total Cost Analysis calculations

Total cost calculations Handymax			
Date	***Fuel price ($/mt)***	***Non ECO-ship per month***	***ECO Design per month***
January-11	494.5	$851,915.64	$786,621.86
February-11	539	$881,294.54	$810,124.98
March-11	597	$919,586.14	$840,758.26
April-11	655	$957,877.74	$871,391.54
May-11	661	$961,838.94	$874,560.50
June-11	637.5	$946,324.24	$862,148.74
July-11	636	$945,333.94	$861,356.50
August-11	663	$963,159.34	$875,616.82
September-11	634	$944,013.54	$860,300.18
October-11	596	$918,925.94	$840,230.10
November-11	635.75	$945,168.89	$861,224.46
December-11	623.75	$937,246.49	$854,886.54

January-12	650.25	$954,741.79	$868,882.78
February-12	659.25	$960,683.59	$873,636.22
March-12	702	$988,907.14	$896,215.06
April-12	714	$996,829.54	$902,552.98
May-12	694.25	$983,790.59	$892,121.82
June-12	579.25	$907,867.59	$831,383.42
July-12	551.5	$889,547.04	$816,726.98
August-12	607.75	$926,683.29	$846,435.98
September-12	655.75	$958,372.89	$871,787.66
October-12	637.75	$946,489.29	$862,280.78
November-12	593.5	$917,275.44	$838,909.70
December-12	587.5	$913,314.24	$835,740.74
January-13	583.75	$910,838.49	$833,760.14
February-13	637.75	$946,489.29	$862,280.78
March-13	616.5	$932,460.04	$851,057.38
April-13	602.5	$923,217.24	$843,663.14

Table 15: Total Cost Analysis and data

Total cost calculations Handymax				
Date	***Non ECO-ship per trip***	***ECO Design per trip***	***Benefit ($)***	***Benefit (%)***
January-11				
February-11	$1,733,210.18	$1,596,746.84	$136,463.34	7.87%
March-11				
April-11	$1,877,463.88	$1,712,149.80	$165,314.08	8.81%
May-11				
June-11	$1,908,163.18	$1,736,709.24	$171,453.94	8.99%
July-11				
August-11	$1,908,493.28	$1,736,973.32	$171,519.96	8.99%
September-11				
October-11	$1,862,939.48	$1,700,530.28	$162,409.20	8.72%
November-11				

December-11	$1,882,415.38	$1,716,111.00	$166,304.38	8.83%
January-12				
February-12	$1,915,425.38	$1,742,519.00	$172,906.38	9.03%
March-12				
April-12	$1,985,736.68	$1,798,768.04	$186,968.64	9.42%
May-12				
June-12	$1,891,658.18	$1,723,505.24	$168,152.94	8.89%
July-12				
August-12	$1,816,230.33	$1,663,162.96	$153,067.37	8.43%
September-12				
October-12	$1,904,862.18	$1,734,068.44	$170,793.74	8.97%
November-12				
December-12	$1,830,589.68	$1,674,650.44	$155,939.24	8.52%
January-13				
February-13	$1,857,327.78	$1,696,040.92	$161,286.86	8.68%
March-13				
April-13	$1,855,677.28	$1,694,720.52	$160,956.76	8.67%

Table 16: Total Cost Analysis and data

Total Cost of Panamax					
Non ECO-ship per month	***ECO Design per month***	***Non ECO-ship per trip***	***ECO Design per trip***	***Benefit ($)***	***Benefit (%)***
$1,142,472.96	$961,282.72				
$1,197,999.08	$1,000,503.55	$2,340,472.04	$1,961,786.27	$378,685.77	16.18%
$1,270,370.21	$1,051,622.84				
$1,342,741.33	$1,102,742.13	$2,613,111.54	$2,154,364.96	$458,746.57	17.56%
$1,350,228.00	$1,108,030.33				
$1,320,905.22	$1,087,318.20	$2,671,133.21	$2,195,348.53	$475,784.68	17.81%
$1,319,033.55	$1,085,996.15				
$1,352,723.55	$1,109,793.06	$2,671,757.10	$2,195,789.21	$475,967.89	17.81%
$1,316,537.99	$1,084,233.42				
$1,269,122.43	$1,050,741.47	$2,585,660.42	$2,134,974.89	$450,685.53	17.43%
$1,318,721.60	$1,085,775.81				
$1,303,748.27	$1,075,199.41	$2,622,469.87	$2,160,975.22	$461,494.65	17.60%
$1,336,814.38	$1,098,555.63				
$1,348,044.39	$1,106,487.93	$2,684,858.77	$2,205,043.57	$479,815.20	17.87%
$1,401,386.90	$1,144,166.37				
$1,416,360.23	$1,154,742.78	$2,817,747.13	$2,298,909.15	$518,837.98	18.41%
$1,391,716.62	$1,137,335.78				
$1,248,222.15	$1,035,978.57	$2,639,938.76	$2,173,314.35	$466,624.41	17.68%
$1,213,596.31	$1,011,520.64				
$1,283,783.82	$1,061,097.53	$2,497,380.13	$2,072,618.17	$424,761.95	17.01%
$1,343,677.16	$1,103,403.15				
$1,321,217.16	$1,087,538.54	$2,664,894.32	$2,190,941.69	$473,952.63	17.79%
$1,266,002.98	$1,048,538.05				
$1,258,516.32	$1,043,249.85	$2,524,519.30	$2,091,787.91	$432,731.39	17.14%
$1,253,837.15	$1,039,944.73				

$1,321,217.16	$1,087,538.54	$2,575,054.31	$2,127,483.27	$447,571.04	17.38%
$1,294,701.88	$1,068,809.50				
$1,277,232.99	$1,056,470.36	$2,571,934.86	$2,125,279.85	$446,655.01	17.37%
$1,259,452.15	$1,043,910.88				
$1,280,352.43	$1,058,673.78	$2,539,804.58	$2,102,584.65	$437,219.93	17.21%
$1,264,131.32	$1,047,216.00				
$1,274,113.54	$1,054,266.94	$2,538,244.86	$2,101,482.94	$436,761.91	17.21%

Table 17: Total Cost Analysis and data

Total Cost of Capesize					
Non ECO-ship per month	**ECO Design per month**	**Non ECO-ship per trip**	**ECO Design per trip**	**Benefit ($)**	**Benefit (%)**
$1,472,206.55	$1,348,148.37				
$1,557,405.36	$1,422,183.20	$3,029,611.91	$2,770,331.56	$259,280.35	8.56%
$1,668,451.00	$1,518,678.03				
$1,779,496.64	$1,615,172.86	$3,447,947.64	$3,133,850.89	$314,096.75	9.11%
$1,790,984.12	$1,625,155.08				
$1,745,991.49	$1,586,058.04	$3,536,975.61	$3,211,213.12	$325,762.49	9.21%
$1,743,119.62	$1,583,562.48				
$1,794,813.28	$1,628,482.49	$3,537,932.90	$3,212,044.98	$325,887.92	9.21%
$1,739,290.46	$1,580,235.08				
$1,666,536.42	$1,517,014.32	$3,405,826.88	$3,097,249.40	$308,577.48	9.06%
$1,742,640.98	$1,583,146.56				
$1,719,666.02	$1,563,182.11	$3,462,306.99	$3,146,328.67	$315,978.32	9.13%
$1,770,402.39	$1,607,270.27				
$1,787,633.61	$1,622,243.60	$3,558,035.99	$3,229,513.87	$328,522.12	9.23%
$1,869,481.90	$1,693,366.95				
$1,892,456.86	$1,713,331.40	$3,761,938.76	$3,406,698.34	$355,240.42	9.44%
$1,854,643.91	$1,680,473.24				
$1,634,467.21	$1,489,147.28	$3,489,111.11	$3,169,620.52	$319,490.59	9.16%
$1,581,337.61	$1,442,979.50				
$1,689,032.74	$1,536,562.85	$3,270,370.35	$2,979,542.34	$290,828.00	8.89%
$1,780,932.58	$1,616,420.64				
$1,746,470.14	$1,586,473.97	$3,527,402.71	$3,202,894.60	$324,508.11	9.20%
$1,661,749.97	$1,512,855.06				
$1,650,262.49	$1,502,872.84	$3,312,012.46	$3,015,727.90	$296,284.56	8.95%
$1,643,082.82	$1,496,633.95				
$1,746,470.14	$1,586,473.97	$3,389,552.95	$3,083,107.92	$306,445.03	9.04%
$1,705,785.31	$1,551,120.26				
$1,678,981.19	$1,527,828.40	$3,384,766.50	$3,078,948.66	$305,817.84	9.04%
$1,651,698.43	$1,504,120.62				
$1,683,767.64	$1,531,987.66	$3,335,466.07	$3,036,108.28	$299,357.79	8.97%
$1,658,878.10	$1,510,359.51				
$1,674,194.74	$1,523,669.14	$3,333,072.84	$3,034,028.65	$299,044.19	8.97%

Table 18: Total Cost Analysis and data

Fuel Price change	Fuel Price	Handymax			
		Non ECO-ship	ECO Design	Handymax Benefit ($)	Handymax Benefit (%)
-40%	360	$1,000,790.74	$905,721.94	$95,068.80	9.50%
-39%	366	$1,008,713.14	$912,059.86	$96,653.28	9.58%
-38%	372	$1,016,635.54	$918,397.78	$98,237.76	9.66%
-37%	378	$1,024,557.94	$924,735.70	$99,822.24	9.74%
-36%	384	$1,032,480.34	$931,073.62	$101,406.72	9.82%
-35%	390	$1,040,402.74	$937,411.54	$102,991.20	9.90%
-34%	396	$1,048,325.14	$943,749.46	$104,575.68	9.98%
-33%	402	$1,056,247.54	$950,087.38	$106,160.16	10.05%
-32%	408	$1,064,169.94	$956,425.30	$107,744.64	10.12%
-31%	414	$1,072,092.34	$962,763.22	$109,329.12	10.20%
-30%	420	$1,080,014.74	$969,101.14	$110,913.60	10.27%
-29%	426	$1,087,937.14	$975,439.06	$112,498.08	10.34%
-28%	432	$1,095,859.54	$981,776.98	$114,082.56	10.41%
-27%	438	$1,103,781.94	$988,114.90	$115,667.04	10.48%
-26%	444	$1,111,704.34	$994,452.82	$117,251.52	10.55%
-25%	450	$1,119,626.74	$1,000,790.74	$118,836.00	10.61%
-24%	456	$1,127,549.14	$1,007,128.66	$120,420.48	10.68%
-23%	462	$1,135,471.54	$1,013,466.58	$122,004.96	10.74%
-22%	468	$1,143,393.94	$1,019,804.50	$123,589.44	10.81%
-21%	474	$1,151,316.34	$1,026,142.42	$125,173.92	10.87%

-20%	480	$1,159,238.74	$1,032,480.34	$126,758.40	10.93%
-19%	486	$1,167,161.14	$1,038,818.26	$128,342.88	11.00%
-18%	492	$1,175,083.54	$1,045,156.18	$129,927.36	11.06%
-17%	498	$1,183,005.94	$1,051,494.10	$131,511.84	11.12%
-16%	504	$1,190,928.34	$1,057,832.02	$133,096.32	11.18%
-15%	510	$1,198,850.74	$1,064,169.94	$134,680.80	11.23%
-14%	516	$1,206,773.14	$1,070,507.86	$136,265.28	11.29%
-13%	522	$1,214,695.54	$1,076,845.78	$137,849.76	11.35%
-12%	528	$1,222,617.94	$1,083,183.70	$139,434.24	11.40%
-11%	534	$1,230,540.34	$1,089,521.62	$141,018.72	11.46%
-10%	540	$1,238,462.74	$1,095,859.54	$142,603.20	11.51%
-9%	546	$1,246,385.14	$1,102,197.46	$144,187.68	11.57%
-8%	552	$1,254,307.54	$1,108,535.38	$145,772.16	11.62%
-7%	558	$1,262,229.94	$1,114,873.30	$147,356.64	11.67%
-6%	564	$1,270,152.34	$1,121,211.22	$148,941.12	11.73%
-5%	570	$1,278,074.74	$1,127,549.14	$150,525.60	11.78%
-4%	576	$1,285,997.14	$1,133,887.06	$152,110.08	11.83%
-3%	582	$1,293,919.54	$1,140,224.98	$153,694.56	11.88%
-2%	588	$1,301,841.94	$1,146,562.90	$155,279.04	11.93%
-1%	594	$1,309,764.34	$1,152,900.82	$156,863.52	11.98%
0%	600	$1,317,686.74	$1,159,238.74	$158,448.00	12.02%
1%	606	$1,325,609.14	$1,165,576.66	$160,032.48	12.07%
2%	612	$1,333,531.54	$1,171,914.58	$161,616.96	12.12%

3%	618	$1,341,453.94	$1,178,252.50	$163,201.44	12.17%
4%	624	$1,349,376.34	$1,184,590.42	$164,785.92	12.21%
5%	630	$1,357,298.74	$1,190,928.34	$166,370.40	12.26%
6%	636	$1,365,221.14	$1,197,266.26	$167,954.88	12.30%
7%	642	$1,373,143.54	$1,203,604.18	$169,539.36	12.35%
8%	648	$1,381,065.94	$1,209,942.10	$171,123.84	12.39%
9%	654	$1,388,988.34	$1,216,280.02	$172,708.32	12.43%
10%	660	$1,396,910.74	$1,222,617.94	$174,292.80	12.48%
11%	666	$1,404,833.14	$1,228,955.86	$175,877.28	12.52%
12%	672	$1,412,755.54	$1,235,293.78	$177,461.76	12.56%
13%	678	$1,420,677.94	$1,241,631.70	$179,046.24	12.60%
14%	684	$1,428,600.34	$1,247,969.62	$180,630.72	12.64%
15%	690	$1,436,522.74	$1,254,307.54	$182,215.20	12.68%
16%	696	$1,444,445.14	$1,260,645.46	$183,799.68	12.72%
17%	702	$1,452,367.54	$1,266,983.38	$185,384.16	12.76%
18%	708	$1,460,289.94	$1,273,321.30	$186,968.64	12.80%
19%	714	$1,468,212.34	$1,279,659.22	$188,553.12	12.84%
20%	720	$1,476,134.74	$1,285,997.14	$190,137.60	12.88%
21%	726	$1,484,057.14	$1,292,335.06	$191,722.08	12.92%
22%	732	$1,491,979.54	$1,298,672.98	$193,306.56	12.96%
23%	738	$1,499,901.94	$1,305,010.90	$194,891.04	12.99%
24%	744	$1,507,824.34	$1,311,348.82	$196,475.52	13.03%
25%	750	$1,515,746.74	$1,317,686.74	$198,060.00	13.07%

26%	756	$1,523,669.14	$1,324,024.66	$199,644.48	13.10%
27%	762	$1,531,591.54	$1,330,362.58	$201,228.96	13.14%
28%	768	$1,539,513.94	$1,336,700.50	$202,813.44	13.17%
29%	774	$1,547,436.34	$1,343,038.42	$204,397.92	13.21%
30%	780	$1,555,358.74	$1,349,376.34	$205,982.40	13.24%
31%	786	$1,563,281.14	$1,355,714.26	$207,566.88	13.28%
32%	792	$1,571,203.54	$1,362,052.18	$209,151.36	13.31%
33%	798	$1,579,125.94	$1,368,390.10	$210,735.84	13.35%
34%	804	$1,587,048.34	$1,374,728.02	$212,320.32	13.38%
35%	810	$1,594,970.74	$1,381,065.94	$213,904.80	13.41%
36%	816	$1,602,893.14	$1,387,403.86	$215,489.28	13.44%
37%	822	$1,610,815.54	$1,393,741.78	$217,073.76	13.48%
38%	828	$1,618,737.94	$1,400,079.70	$218,658.24	13.51%
39%	834	$1,626,660.34	$1,406,417.62	$220,242.72	13.54%
40%	840	$1,634,582.74	$1,412,755.54	$221,827.20	13.57%

Table 19: Total Cost Analysis and data

Panamax			
Non ECO-ship	***ECO Design***	***Panamax Benefit ($)***	***Pamax Benefit (%)***
$1,423,846.90	$1,160,030.98	$263,815.92	18.53%
$1,438,820.24	$1,170,607.38	$268,212.85	18.64%
$1,453,793.57	$1,181,183.79	$272,609.78	18.75%
$1,468,766.91	$1,191,760.19	$277,006.72	18.86%
$1,483,740.24	$1,202,336.60	$281,403.65	18.97%
$1,498,713.58	$1,212,913.00	$285,800.58	19.07%
$1,513,686.92	$1,223,489.40	$290,197.51	19.17%
$1,528,660.25	$1,234,065.81	$294,594.44	19.27%

$1,543,633.59	$1,244,642.21	$298,991.38	19.37%
$1,558,606.92	$1,255,218.62	$303,388.31	19.47%
$1,573,580.26	$1,265,795.02	$307,785.24	19.56%
$1,588,553.60	$1,276,371.42	$312,182.17	19.65%
$1,603,526.93	$1,286,947.83	$316,579.10	19.74%
$1,618,500.27	$1,297,524.23	$320,976.04	19.83%
$1,633,473.60	$1,308,100.64	$325,372.97	19.92%
$1,648,446.94	$1,318,677.04	$329,769.90	20.00%
$1,663,420.28	$1,329,253.44	$334,166.83	20.09%
$1,678,393.61	$1,339,829.85	$338,563.76	20.17%
$1,693,366.95	$1,350,406.25	$342,960.70	20.25%
$1,708,340.28	$1,360,982.66	$347,357.63	20.33%
$1,723,313.62	$1,371,559.06	$351,754.56	20.41%
$1,738,286.96	$1,382,135.46	$356,151.49	20.49%
$1,753,260.29	$1,392,711.87	$360,548.42	20.56%
$1,768,233.63	$1,403,288.27	$364,945.36	20.64%
$1,783,206.96	$1,413,864.68	$369,342.29	20.71%
$1,798,180.30	$1,424,441.08	$373,739.22	20.78%
$1,813,153.64	$1,435,017.48	$378,136.15	20.86%
$1,828,126.97	$1,445,593.89	$382,533.08	20.92%
$1,843,100.31	$1,456,170.29	$386,930.02	20.99%
$1,858,073.64	$1,466,746.70	$391,326.95	21.06%
$1,873,046.98	$1,477,323.10	$395,723.88	21.13%
$1,888,020.32	$1,487,899.50	$400,120.81	21.19%
$1,902,993.65	$1,498,475.91	$404,517.74	21.26%
$1,917,966.99	$1,509,052.31	$408,914.68	21.32%
$1,932,940.32	$1,519,628.72	$413,311.61	21.38%
$1,947,913.66	$1,530,205.12	$417,708.54	21.44%
$1,962,887.00	$1,540,781.52	$422,105.47	21.50%
$1,977,860.33	$1,551,357.93	$426,502.40	21.56%
$1,992,833.67	$1,561,934.33	$430,899.34	21.62%
$2,007,807.00	$1,572,510.74	$435,296.27	21.68%
$2,022,780.34	$1,583,087.14	$439,693.20	21.74%
$2,037,753.68	$1,593,663.54	$444,090.13	21.79%
$2,052,727.01	$1,604,239.95	$448,487.06	21.85%
$2,067,700.35	$1,614,816.35	$452,884.00	21.90%
$2,082,673.68	$1,625,392.76	$457,280.93	21.96%
$2,097,647.02	$1,635,969.16	$461,677.86	22.01%
$2,112,620.36	$1,646,545.56	$466,074.79	22.06%

$2,127,593.69	$1,657,121.97	$470,471.72	22.11%
$2,142,567.03	$1,667,698.37	$474,868.66	22.16%
$2,157,540.36	$1,678,274.78	$479,265.59	22.21%
$2,172,513.70	$1,688,851.18	$483,662.52	22.26%
$2,187,487.04	$1,699,427.58	$488,059.45	22.31%
$2,202,460.37	$1,710,003.99	$492,456.38	22.36%
$2,217,433.71	$1,720,580.39	$496,853.32	22.41%
$2,232,407.04	$1,731,156.80	$501,250.25	22.45%
$2,247,380.38	$1,741,733.20	$505,647.18	22.50%
$2,262,353.72	$1,752,309.60	$510,044.11	22.54%
$2,277,327.05	$1,762,886.01	$514,441.04	22.59%
$2,292,300.39	$1,773,462.41	$518,837.98	22.63%
$2,307,273.72	$1,784,038.82	$523,234.91	22.68%
$2,322,247.06	$1,794,615.22	$527,631.84	22.72%
$2,337,220.40	$1,805,191.62	$532,028.77	22.76%
$2,352,193.73	$1,815,768.03	$536,425.70	22.81%
$2,367,167.07	$1,826,344.43	$540,822.64	22.85%
$2,382,140.40	$1,836,920.84	$545,219.57	22.89%
$2,397,113.74	$1,847,497.24	$549,616.50	22.93%
$2,412,087.08	$1,858,073.64	$554,013.43	22.97%
$2,427,060.41	$1,868,650.05	$558,410.36	23.01%
$2,442,033.75	$1,879,226.45	$562,807.30	23.05%
$2,457,007.08	$1,889,802.86	$567,204.23	23.09%
$2,471,980.42	$1,900,379.26	$571,601.16	23.12%
$2,486,953.76	$1,910,955.66	$575,998.09	23.16%
$2,501,927.09	$1,921,532.07	$580,395.02	23.20%
$2,516,900.43	$1,932,108.47	$584,791.96	23.23%
$2,531,873.76	$1,942,684.88	$589,188.89	23.27%
$2,546,847.10	$1,953,261.28	$593,585.82	23.31%
$2,561,820.44	$1,963,837.68	$597,982.75	23.34%
$2,576,793.77	$1,974,414.09	$602,379.68	23.38%
$2,591,767.11	$1,984,990.49	$606,776.62	23.41%
$2,606,740.44	$1,995,566.90	$611,173.55	23.45%
$2,621,713.78	$2,006,143.30	$615,570.48	23.48%

Table 20: Total Cost Analysis and data

Total Cost of Capesize			
Non ECO-ship	***ECO Design***	***Capesize Benefit ($)***	***Capesize Benefit (%)***
$1,903,944.34	$1,723,313.62	$180,630.72	9.49%
$1,926,919.30	$1,743,278.07	$183,641.23	9.53%
$1,949,894.26	$1,763,242.52	$186,651.74	9.57%
$1,972,869.22	$1,783,206.96	$189,662.26	9.61%
$1,995,844.18	$1,803,171.41	$192,672.77	9.65%
$2,018,819.14	$1,823,135.86	$195,683.28	9.69%
$2,041,794.10	$1,843,100.31	$198,693.79	9.73%
$2,064,769.06	$1,863,064.76	$201,704.30	9.77%
$2,087,744.02	$1,883,029.20	$204,714.82	9.81%
$2,110,718.98	$1,902,993.65	$207,725.33	9.84%
$2,133,693.94	$1,922,958.10	$210,735.84	9.88%
$2,156,668.90	$1,942,922.55	$213,746.35	9.91%
$2,179,643.86	$1,962,887.00	$216,756.86	9.94%
$2,202,618.82	$1,982,851.44	$219,767.38	9.98%
$2,225,593.78	$2,002,815.89	$222,777.89	10.01%
$2,248,568.74	$2,022,780.34	$225,788.40	10.04%
$2,271,543.70	$2,042,744.79	$228,798.91	10.07%
$2,294,518.66	$2,062,709.24	$231,809.42	10.10%
$2,317,493.62	$2,082,673.68	$234,819.94	10.13%
$2,340,468.58	$2,102,638.13	$237,830.45	10.16%
$2,363,443.54	$2,122,602.58	$240,840.96	10.19%
$2,386,418.50	$2,142,567.03	$243,851.47	10.22%
$2,409,393.46	$2,162,531.48	$246,861.98	10.25%
$2,432,368.42	$2,182,495.92	$249,872.50	10.27%
$2,455,343.38	$2,202,460.37	$252,883.01	10.30%
$2,478,318.34	$2,222,424.82	$255,893.52	10.33%
$2,501,293.30	$2,242,389.27	$258,904.03	10.35%
$2,524,268.26	$2,262,353.72	$261,914.54	10.38%
$2,547,243.22	$2,282,318.16	$264,925.06	10.40%
$2,570,218.18	$2,302,282.61	$267,935.57	10.42%
$2,593,193.14	$2,322,247.06	$270,946.08	10.45%
$2,616,168.10	$2,342,211.51	$273,956.59	10.47%
$2,639,143.06	$2,362,175.96	$276,967.10	10.49%
$2,662,118.02	$2,382,140.40	$279,977.62	10.52%
$2,685,092.98	$2,402,104.85	$282,988.13	10.54%

$2,708,067.94	$2,422,069.30	$285,998.64	10.56%
$2,731,042.90	$2,442,033.75	$289,009.15	10.58%
$2,754,017.86	$2,461,998.20	$292,019.66	10.60%
$2,776,992.82	$2,481,962.64	$295,030.18	10.62%
$2,799,967.78	$2,501,927.09	$298,040.69	10.64%
$2,822,942.74	$2,521,891.54	$301,051.20	10.66%
$2,845,917.70	$2,541,855.99	$304,061.71	10.68%
$2,868,892.66	$2,561,820.44	$307,072.22	10.70%
$2,891,867.62	$2,581,784.88	$310,082.74	10.72%
$2,914,842.58	$2,601,749.33	$313,093.25	10.74%
$2,937,817.54	$2,621,713.78	$316,103.76	10.76%
$2,960,792.50	$2,641,678.23	$319,114.27	10.78%
$2,983,767.46	$2,661,642.68	$322,124.78	10.80%
$3,006,742.42	$2,681,607.12	$325,135.30	10.81%
$3,029,717.38	$2,701,571.57	$328,145.81	10.83%
$3,052,692.34	$2,721,536.02	$331,156.32	10.85%
$3,075,667.30	$2,741,500.47	$334,166.83	10.86%
$3,098,642.26	$2,761,464.92	$337,177.34	10.88%
$3,121,617.22	$2,781,429.36	$340,187.86	10.90%
$3,144,592.18	$2,801,393.81	$343,198.37	10.91%
$3,167,567.14	$2,821,358.26	$346,208.88	10.93%
$3,190,542.10	$2,841,322.71	$349,219.39	10.95%
$3,213,517.06	$2,861,287.16	$352,229.90	10.96%
$3,236,492.02	$2,881,251.60	$355,240.42	10.98%
$3,259,466.98	$2,901,216.05	$358,250.93	10.99%
$3,282,441.94	$2,921,180.50	$361,261.44	11.01%
$3,305,416.90	$2,941,144.95	$364,271.95	11.02%
$3,328,391.86	$2,961,109.40	$367,282.46	11.03%
$3,351,366.82	$2,981,073.84	$370,292.98	11.05%
$3,374,341.78	$3,001,038.29	$373,303.49	11.06%
$3,397,316.74	$3,021,002.74	$376,314.00	11.08%
$3,420,291.70	$3,040,967.19	$379,324.51	11.09%
$3,443,266.66	$3,060,931.64	$382,335.02	11.10%
$3,466,241.62	$3,080,896.08	$385,345.54	11.12%
$3,489,216.58	$3,100,860.53	$388,356.05	11.13%
$3,512,191.54	$3,120,824.98	$391,366.56	11.14%
$3,535,166.50	$3,140,789.43	$394,377.07	11.16%
$3,558,141.46	$3,160,753.88	$397,387.58	11.17%
$3,581,116.42	$3,180,718.32	$400,398.10	11.18%

$3,604,091.38	$3,200,682.77	$403,408.61	11.19%
$3,627,066.34	$3,220,647.22	$406,419.12	11.21%
$3,650,041.30	$3,240,611.67	$409,429.63	11.22%
$3,673,016.26	$3,260,576.12	$412,440.14	11.23%
$3,695,991.22	$3,280,540.56	$415,450.66	11.24%
$3,718,966.18	$3,300,505.01	$418,461.17	11.25%
$3,741,941.14	$3,320,469.46	$421,471.68	11.26%

Table 20: Total Cost Analysis

Appendix 3

Cost-benefit analysis data

Ecoships					
Date Sale	**Months up to next August**	**Years up to August 2013**	**Vessel Type**	**Vessel DWT**	**Year Built**
April 2013	4	0	BC	79252	2012
March 2013	5	0	BC	75200	2012
February 2013	6	0	BC	81998	2013
January 2013	7	0	BC	81998	2013
February 2013	6	0	BC	75200	2013
February 2013	6	0	BC	75200	2013
May 2012	3	1	BC	79200	2011
January 2013	7	0	BC	81545	2013
August 2012	8	1	BC	79393	2012
May 2012	3	1	BC	79252	2012
June 2012	2	1	BC	76116	2012
April 2013	4	0	BC	82500	2013
May 2013	3	0	BC	82500	2013
May 2012	3	1	BC	76098	2011
April 2013	4	0	BC	81600	2013
November 2011	9	2	BC	79393	2012
September 2013	-1	0	BC	75200	2011
June 2013	2	0	BC	81588	2014
November 2011	9	2	BC	75200	2011
March 2011	5	2	BC	82154	2010

Table 22, Cost Benefit Analysis Data

Ecoships					
Sell Price	**Average bought Price of an ecoship**	**Average building years of an eco ship**	**Present Value of current proces**	**Rf**	**Present Value of the ecoship**
$19,000,000.00	$41,500,000.00	4	$19,011,400.00	0.06%	$22,409,039.38
$20,000,000.00	$40,000,000.00	4	$20,012,000.00	0.06%	$19,911,315.06
$21,500,000.00	$42,000,000.00	4	$21,512,900.00	0.06%	$20,406,580.82
$21,500,000.00	$42,000,000.00	4	$21,512,900.00	0.06%	$20,406,580.82
$21,500,000.00	$40,200,000.00	4	$21,512,900.00	0.06%	$18,610,031.64
$21,500,000.00	$40,200,000.00	4	$21,512,900.00	0.06%	$18,610,031.64
$22,400,000.00	$41,500,000.00	4	$22,426,888.06	0.06%	$18,993,551.31
$22,500,000.00	$42,000,000.00	4	$22,513,500.00	0.06%	$19,405,980.82
$23,000,000.00	$41,500,000.00	4	$23,027,608.28	0.06%	$18,392,831.10
$24,000,000.00	$41,500,000.00	4	$24,028,808.64	0.06%	$17,391,630.74
$24,000,000.00	$40,000,000.00	4	$24,028,808.64	0.06%	$15,894,506.42
$24,900,000.00	$42,000,000.00	4	$24,914,940.00	0.06%	$17,004,540.82
$26,000,000.00	$42,000,000.00	4	$26,015,600.00	0.06%	$15,903,880.82
$26,000,000.00	$40,700,000.00	4	$26,031,209.36	0.06%	$14,590,763.72
$28,000,000.00	$42,000,000.00	4	$28,016,800.00	0.06%	$13,902,680.82
$28,500,000.00	$41,000,000.00	4	$28,551,330.79	0.06%	$12,370,067.15
$30,300,000.00	$40,200,000.00	4	$30,354,572.73	0.06%	$9,768,358.91
$30,600,000.00	$42,000,000.00	4	$30,618,360.00	0.06%	$11,301,120.82
$31,000,000.00	$40,200,000.0	4	$31,055,833.49	0.06%	$9,067,098.

	0				15
$42,500,000.00	$42,000,000.0 0	4	$42,576,545.91	0.06%	- $657,065.09

Table 23, Cost and Benefit Analysis Data