# OPERATIONAL APPROACH TO IMPROVE ENERGY EFFICIENCY OF FAR EAST – THE MEDITERRANEAN SEA CONTAINER ROUTE

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# ABSTRACT

So far, the main problem of maritime sector was only transporting cargoes from pillar to post specifically in terms of economic. However, at the present time, saving energy and reducing exhaust emissions are added to this issue by the effect of global warming. In other words, today's problem of maritime sector is to create economic transportation as well as environmentalist consideration.

Global warming, which is one of the world's most remarkable and controversial issues, encumbers maritime sector compared to others. The most significant reason of this is that energy saving can be provided up to 75% with the aid of technological, operational and political regulations.

With the importance of this subject, the maritime sector will be analysed in details with regards to the energy saving and being able to use the energy more efficiently. The content of the study is formed by energy efficiency, regulations, technological and operational measures. These mentioned titles will be tried to report by analysing in chapters.

After this analysis, in order to understand the importance of these regulations, a case study will be evaluated by focusing on more efficient Far East – the Mediterranean Sea container transport. In the case study, a hub port system will be generated and a fleet, which is formed by using larger container vessels, will be adapted to hub port system. The energy efficiency analysis will be performed by using numerical methods.

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# LIST OF ABBREVIATIONS

AFC: Alkaline Fuel Cells

AHP: Analytic Hierarchy Process

B100: 100% biodiesel

B20: Biodiesel - a mixture composed of 20% of biodiesel with 80% of diesel

CEO: Chief Executive Officer

CH4: Tetrahydridocarbon - Methane

CNSS: Clean North Sea Shipping

$CO_2$: Carbon Dioxide

DNV: Det Norske Veritas

DWT: Deadweight Tonnage

EEDI: Energy Efficiency Design Index

EEOI: Energy Efficiency Operational Indicator

EPA: United States Environmental Protection Agency

ESP: Energy Saving Potential

GHG: Greenhouse gas

GT: Gross Tonnage

HFC: Hydro fluorocarbons

HFO: Heavy Fuel Oil

HVAC: Heating, Ventilation and Air Conditioning

ICAO: International Civil Aviation Organization

ICS: International Chamber of Shipping

IMO: International Maritime Organization

IPCC: Intergovernmental Panel on Climate Change

JOC: Journal of Commerce

LNG: Liquid Natural Gas

MARPOL: International Convention for the Prevention of Pollution from Ships

MBM: Market Based Measures

MBM-EG: Market Based Measures – Expert Group

MCFC: Molten Carbonate Fuel Cells

MEPC: Marine Environment Protection Committee

MTO: Multi-Modal Transport Operators

NIMA: National Imagery and Mapping Agency

NM: Nautical Mile

NO2: Nitrogen Dioxide

$NO_x$: Nitrogen Oxides

PEMFC: Polymer Electrolyte Membrane Fuel Cells

SEEMP: Ship Energy Efficiency Management Plan

SOFC: Solid Oxide Fuel Cells

$SO_x$: Sulphur Oxides

TARGETS: Targeted Advanced Research for Global Efficiency of Transportation Shipping

TEU: Twenty-foot Equivalent Unit

ULCV: Ultra Large Container Carrier

UN: United Nations

UNCTAD: United Nations Conference on Trade and Development

UNEP: The United Nations Environment Programme

UNFCCC: United Nations Framework Convention on Climate Change

USA: United States of America

VLCC: Very Large Crude Oil Carrier

# 1. INTRODUCTION

The maritime industry is at the heart of our understanding of the global economy, because the maritime industry is both one of the industries which are affected first, and affecting the global economy and the global developments directly and indirectly. The reason of this impact is that the maritime industry has a large volume in the world economy. However, this large volume of shipping industry brings with it some problems. One of these problems is ship related environmental issues.

One of the most significant current discussions in the maritime sector is to reduce greenhouse gases (GHG) emissions from international commercial vessels. In this frame, International Maritime Organization (IMO) proposed and adopted a new chapter to Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) that includes some technical and operational measures to reduce GHG emissions. This development is influencing the maritime industry to seek for solutions to decrease the emissions and improve efficiency.

The maritime industry might be considered as comprising four branches with the following titles; users of shipping's services, operators of ships, manufacturers of ships and equipment and makers of rules and regulations. This approach is very important to understand the perspective of people in each part to events. An excellent example is ship operators which aim for continuous ship operations and adopt a principle of zero environmental damage. This aim is supported by the economies of scale and the current regulations required more efficient and greener ships.

This project will focus on the current operational solutions to reduce GHG emissions from ships and increasing of the energy efficiency. In the pages that follow, it will analysed that the aid of the current operational solutions to reduce emissions from ships and also which solutions are trending since IMO's Energy Efficiency Design Index (EEDI) was adopted. This paper has been divided into six parts. The first part gives a brief overview of the recent history of gas emissions, energy efficiency and adopted regulations. Then, the second part begins by describing possible solutions to reduce emissions from ships. It will then go on to methodology, case study, results & discussion and conclusion parts.

# 2. LITERATURE REVIEW

Today, the reduction of carbon dioxide $CO_2$ emissions from worldwide industry, transport and other activities is one of the biggest problems of mankind, and its importance tends to be increase relating to the growth earth's population. It is expected that world population could reach 8.9 billion by 2050 (UN, 2004), and hence the demand for energy will increase incrementally compared with today's energy demand. Moreover, $CO_2$ emissions cause greenhouse gas (GHG) concentrations in the atmosphere that will continue to increase unless our annual emissions decrease to a large extent (EPA, 2013) and will impact our food supply, water resources, infrastructure, ecosystems and egregiously our own health. Therefore, it is compulsory to reduce the overall $CO_2$ emissions in order to create a more liveable environment. Because of the vital importance of gas emissions, marine sector has responsibility just as weighty as other sectors. The following table illustrates the results obtained from preliminary analysis of GHG emissions from shipping.

| | **International Shipping (million tonnes)** | **Total Shipping** | |
|---|---|---|---|
| | | **Million tonnes** | **$CO_2$ Equivalent** |
| $CO_2$ | 870 | 1050 | 1050 |
| $CH_4$ | Not Determined | 0.24 | 6 |
| $N_2O$ | 0.02 | 0.03 | 9 |
| HFC | Not Determined | 0.0004 | ≤6 |

**Table 1 - Summary of GHG emissions from shipping during 2007 (IMO, 2009d)**

In 2007, estimated $CO_2$ emission from shipping was 3.3% of the global emissions, which was equal to 1,046 million tonnes of $CO_2$. The pie chart below shows some of the main categories of the global $CO_2$ emissions, and data from this chart can be compared with global total emissions which shows $CO_2$ emissions from international shipping is 2.7% and this figure is concurrently equal to 870 million tonnes of $CO_2$ emissions (IMO, 2009d).

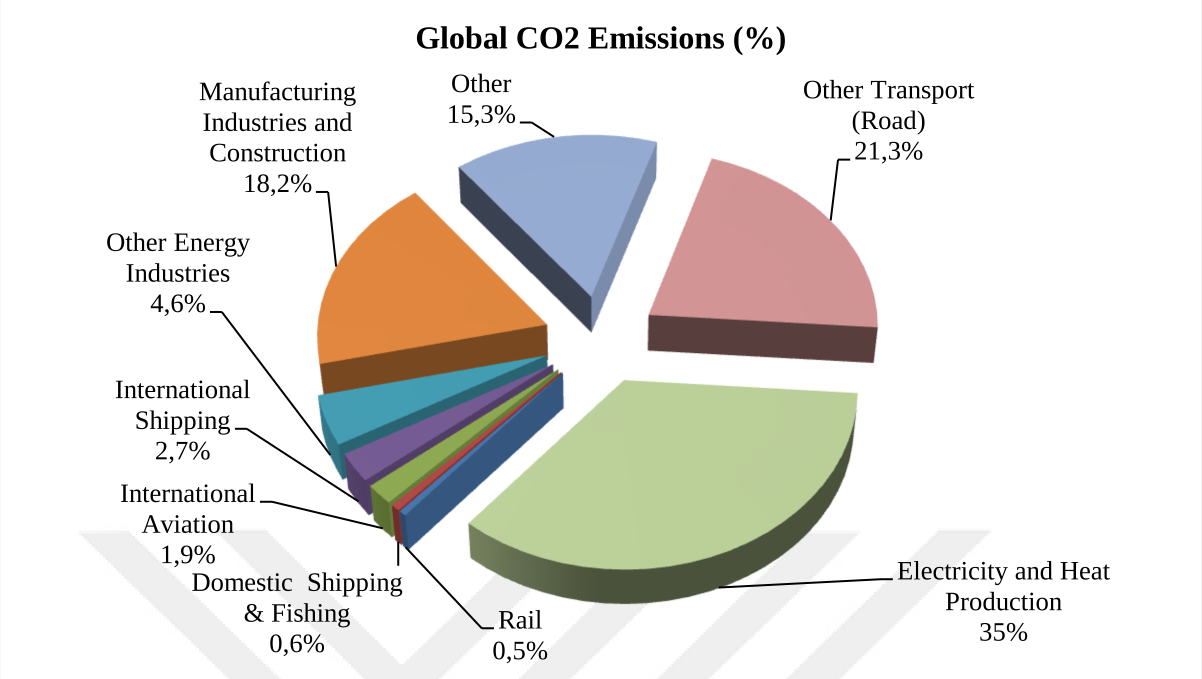



**Figure 1 - Emissions of $CO_2$ from shipping compared with global total emissions (IMO, 2009e)**

In brief, the biggest source of emissions from ships is exhaust gases, and $CO_2$ can be described as the most important GHG emitted by ships, which can be seen at the table 1, when compared with other GHG emissions from ships in terms of quantity and of global warming potential (IMO, 2009d). While the situation is like mentioned above, IMO research findings into GHG emissions and IMO scenarios show that by 2050, as a result of growth in shipping, $CO_2$ emissions from international shipping will increase without policies to reduce GHG emissions form ships. The following figure shows international shipping $CO_2$ emissions scenario, illustrating that all except the ‘minimum’ trajectory in the graph shows that $CO_2$ emissions from ships will increase dramatically. The increase of $CO_2$ emissions is connected to the expected growth of seaborne transport. The best-case scenario illustrates a decrease in emissions by 2050 when compared to emissions in 2007.

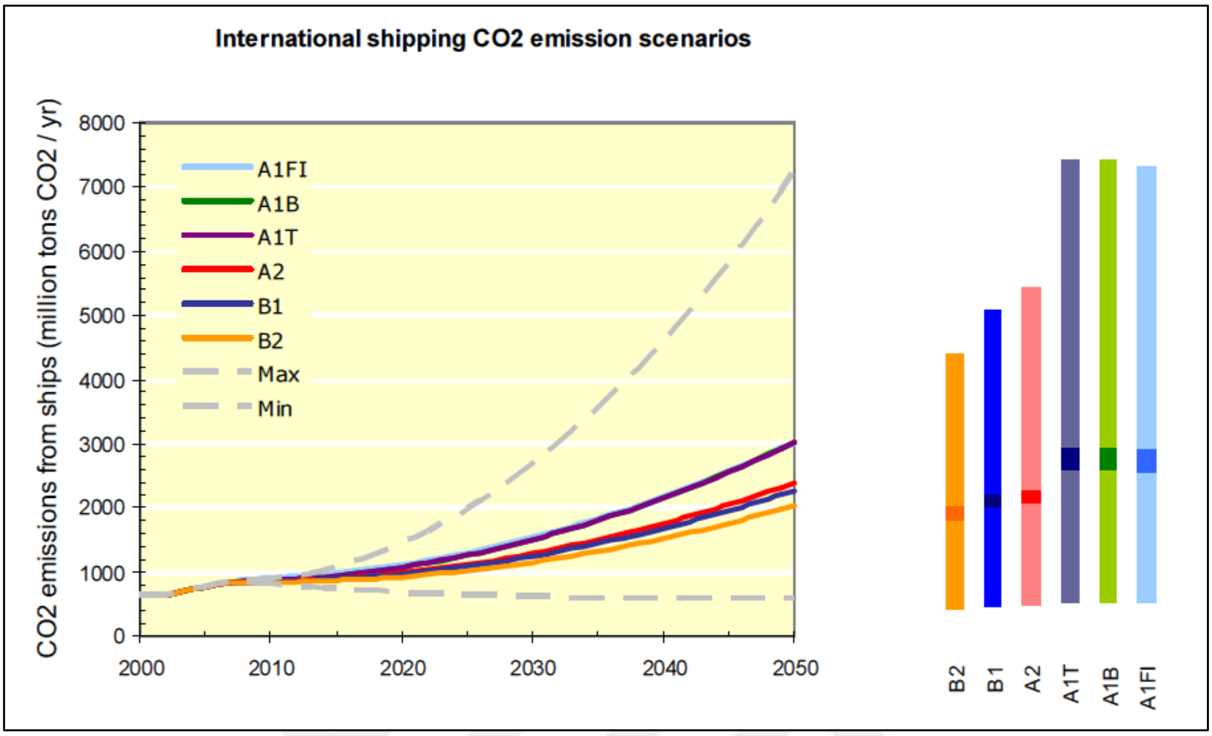



**Figure 2 - Trajectories of the emissions from international shipping. Columns on the right-hand side indicate the range of results for the scenarios within individual families of scenario (IMO, 2009d).**

## 2.1. Energy Efficiency

Energy plays a vital role in our daily lives. It is one of the main elements required to produce food, to perform transportation activities and to integrate technologies. In short terms, energy is one of the indispensable factors of our current modern lives. However, energy developments could place greater pressure on world's resources, such as energy, fresh water and food. Additional, as a result of climate change, the importance of energy is increasing by the day. This chapter reviews the literature concerning the usefulness of improving energy efficiency.

As a consequence of the importance of energy, the energy efficiency is a major subject interesting everyone in the world as well as in the shipping industry. In recent years, there has been an increasing amount of literature on energy efficiency. Numerous studies have attempted to explain energy efficiency and environmental performances, which are today's driving forces for ship operators who pursue cost reductions and greener operations (Marzi et al., 2011).

One of the most important studies is the TARGETS project (Targeted Advanced Research for Global Efficiency of Transportation Shipping), and within the context of the project, Marzi et al. note that emissions from ships are directly related to the energy efficiency of ship operations (2011). It can be said that the first step of efficiency is to save energy, after which the second step is to adopt additional technologies to reduce emissions. Marzi et al. (2011) described the energy efficiency approach and the significant improvements in order to improve the energy efficiency of ships. According to the approach and improvements, energy efficiency can be achieved when applying advanced design and operational management techniques in a close relationship with dynamic energy modelling. The results of these studies indicate that hydrodynamic efficiency largely determines ship energy consumption, and IMO GHG Study (2009) shows that nearly 80% of hydrodynamic efficiency is related ship resistance and propulsive efficiency. The below figure provides data that practically available energy on board an ocean going cargo ship is applied to overcoming hydrodynamic forces (IMO, 2009d). To determine the effect of ship resistance on the hydrodynamic efficiency, Marzi et al. (2011) described the different components of ship resistance, which are the pressure or form related wave resistance, viscous drag and the added resistance due to wind and waves; these need to be roughly 70% of power required on board of a merchant vessel. These components need to be considered in different stages of a vessel's life cycle.

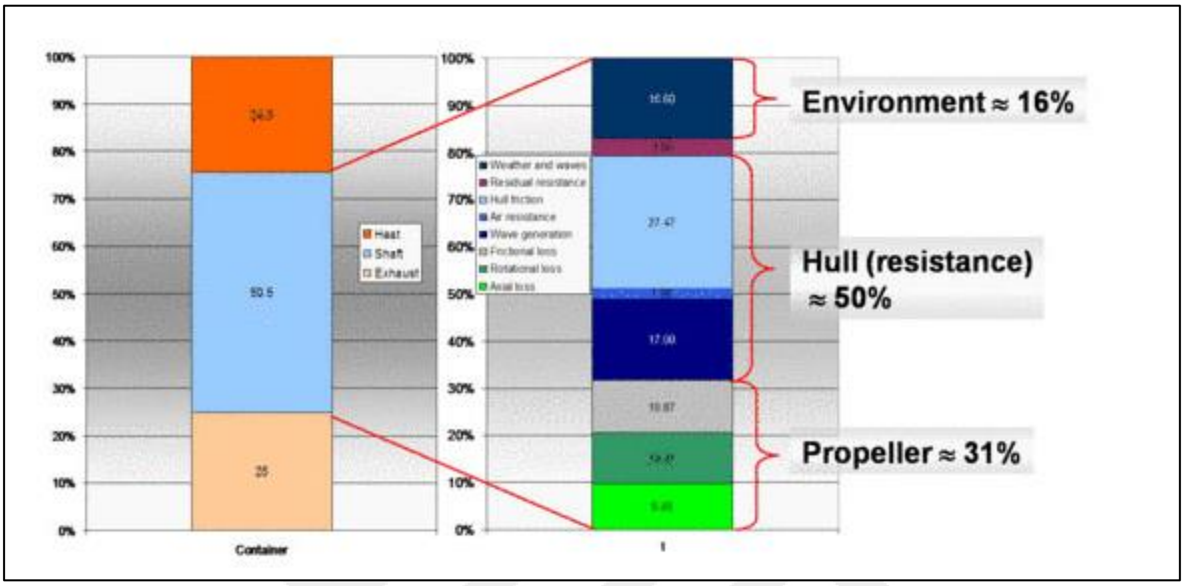



**Figure 3 - Details of cargo vessel energy consumption (IMO, 2009a)**

Marzi et al. also described another component which effects hydrodynamic efficiency as ship propulsion. The ship propulsion provides the second largest hydrodynamic efficiency contribution.

Studies offer another useful method to improve the energy efficiency ships; this method is described by Marzi et al. (2011) as the use of auxiliary energy on board a cargo vessel. This method is based on the improvement of the performance and energy efficiency of ocean going vessels by reducing GHG emissions, and the improvement need to use environmentally friendly fuels and alternative energy sources such as natural gas, bio fuels, hydrogen, and solar energy.

We now come to energy audit and energy saving potentials. Although, to perform energy audits and to determine energy saving potentials are very important to advance the energy efficiency of ships, they have only recently been applied to ships because of the relatively small rate of $CO_2$ emissions that shipping industry contributed to global rates.

| Operation Modes | |
|---|---|
| Alongside | 1,8% |
| Pilotage | 2,3% |
| Discharging | 4,9% |
| Loading | 5,5% |
| Anchored - Drifting | 13,3% |
| Sea Passage Ballast | 32,8% |
| Sea Passage Laden | 39,4% |
| Total: | 100,0% |

**Table 2 – Operation Modes in Percentage (IMO, 2009d)**

The reason of initiation of this concept is the international legislation for emissions from ships has been put into force. The implementation of the concept may lead a performance optimization, a reduction in fuel consumption and/or economic benefits by regular tracking ship operator. According to TARGETS project, the aim of this concept is to appear energy saving potentials of ships with the aid of energy audit on board. The most appropriate implementation place is on board ships and the most appropriate time is the voyage duration of a ship. From the table above we can see operation modes as percentage of total voyage duration time. To ensure maximum energy saving, the operation modes should have analysed perfectly, and in the light of collected results from on board ESPs (Energy Saving Potentials) investigation the best possible technologies should have applied.

## 2.2. Regulations

Ships have a close relationship with their environment such as water and air; from their construction, through operation, until decommission and recycling. However, the world fleet size of ships and its effect on the environment are increasing with each passing day, considering that the environment is a finite resource. Therefore, the ships need to be friendly to the environment.

There is a large volume of published studies, conventions and regulations describing the role of ships on environmental issues. One of the most important of these studies is MARPOL 73/78 which is the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978. It was designed to minimize pollution of the seas, including dumping, oil and exhaust pollution. The objective of this convention is to prevent the marine damage to the environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances. MARPOL contains 6 annexes which are concerned with preventing different forms of marine pollution from ships;

- Annex I: Oil
- Annex II: Noxious Liquid Substances carried in Bulk
- Annex III: Harmful Substances carried in Packaged Form
- Annex IV: Sewage
- Annex V: Garbage
- Annex VI: Air Pollution

During the past 40 years much more information has become available on GHG emission. Evidence was first found in the 1960s and 70s about increasing carbon dioxide concentrations in the atmosphere (IMO, 2013). After some years, in 1988, an Intergovernmental Panel on Climate Change (IPCC) was activated by the World Meteorological Organization and the United Nations Environment Programme (UNEP), which established first analysis in 1990 and this report accepted that global warming was real. The panel’s findings encouraged governments to create the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. After 5 years, an international agreement which is the Kyoto Protocol, adjoined to the UNFCCC. The protocol' aim is to reduce GHG emissions from international aviation and shipping. Related organizations for aviation and shipping are International Civil Aviation Organization (ICAO) and International Maritime Organization (IMO) respectively, with ICAO and IMO reporting their work to UNFCCC regularly.

In recent years, there has been an increasing amount of developments on GHG emission and energy efficiency. In 1997, IMO started to work on GHG emissions with an International Conference of Parties to the MARPOL Convention, which linked the Protocol of 1997 to amend the MARPOL Convention (MARPOL Annex VI). Also, resolution 8 was created about $CO_2$ emissions from ships. As a result of this resolution, the Marine Environment Protection Committee (MEPC) was invited to produce $CO_2$ reduction strategies and the IMO put in action $CO_2$ emissions studies from ships to clarify the amount and relative rate of $CO_2$ emissions as part of the global inventory of $CO_2$ emissions.

In 2000, IMO completed the first GHG study on GHG emissions from ships (IMO, 2000). According to this study, about 1.8 per cent of the global $CO_2$ emissions were ship-sourced in 1996. After this result, the adoption of resolution A.963 (23) occurred to identify and develop the mechanism needed to achieve the reduction and limitation of GHG emissions from international shipping in 2003. During this process, IMO's relevant meetings to reduce GHG emissions from ships are chronically listed below.

- MEPC 53 / July 2005
- The First Intersessional Meeting of IMO's Working Group on Greenhouse Gas Emissions from ships / June 2008
- MEPC 58 / October 2008
- The Second Intersessional Meeting of IMO's Working Group on Greenhouse Gas Emissions from ships / March 2009
- MEPC 59 / July 2009
- MEPC 60 / March 2010
- MEPC 61 / September – October 2010
- The Third Intersessional Meeting of IMO's Working Group on Greenhouse Gas Emissions from ships / March 2011
- MEPC 62 / July 2011

As a summary of IMO's relevant meetings to reduce GHG emissions from ships, during this process which was between 2005 and March 2012, IMO presented the Second IMO GHG Study which was an updated study published in 2009. It shows the emissions from international shipping and compares it to other types of transport. This study was one step ahead of the original investigation and paved the way for future shipping emissions.

The Second GHG Study shows that international shipping is only responsible for 2.7% of global total emissions, and demonstrates that shipping is one of the most efficient transport types when compared to other types. However, the same study indicates that the growth of emissions from international shipping will occur by between 150% to 250%, in the absence of reduction of GHG emissions from international shipping, by 2050. It can be clearly seen that it was imperative to take action.

A considerable amount of literature, studies and regulations have been published and adopted on the prevention of pollution by limiting $NO_x$ and $SO_x$ by IMO. However, this study set out with the aim of assessing the importance of $CO_2$ in greenhouse gas emitted from ships. Also, the study showed that the potential of reduced $CO_2$ emissions by technical and operational measures, and figure could reach up to 75% less $CO_2$ emissions from ships.

As mentioned above, the Marine Environment Protection Committee (MEPC) on its 62nd session adopted the amendments to MARPOL Annex VI, added a new chapter 4 with Regulations on Energy Efficiency for ships. According to this new implementation, all merchant ships, which are equal to 400 gross tonnages and above, must act in accordance with new regulations. Energy Efficiency Design Index (EEDI) is mandatory for new ships, and the Ship's Energy Efficiency Management Plan (SEEMP) which includes Energy Efficiency Operational Indicator (EEOI), is required for all ships in operation. These regulations came into force on 1$^{st}$ January 2013.

## 2.3. Measures to Control $CO_2$ Emissions

Reynolds (2011) mentions in his paper two kinds of measures which have been developed and adopted by IMO to control $CO_2$ emissions:

- Technical and operational measures that aim to improve energy efficiency of ships.
- Market Based Measures (MBMs) that aims to stabilize and reduce GHG emissions from international shipping.

The implementation of measures may reduce GHG emissions on a ship by ship basis are not counteracted by increased emissions associated with the predicted future growth in the world fleet and increased shipping activity. (IMO, 2009d)

### *2.3.1. Technical and Operational Measures*

According IMO's study on GHG emissions (IMO, 2009d), the usage of alternative low or no carbon fuels on ship will have a significant effect on $CO_2$ emissions from ships. This is generally accepted and several studies continue to develop suitable low or no carbon fuels to use on ships. However, it will take time, so the development of technical and operational measures can be important to create energy efficient ships. In this context, by reason of positive experimentation from voluntary implementation of measures, these measures are put into practice by IMO on 1st January 2013 and they can be described as EEDI (Energy Efficiency Design Index), SEEMP (Ship's Energy Efficiency Management Plan) and EEOI (Energy Efficiency Operational Indicator).

#### *2.3.1.1. Energy Efficiency Design Index (EEDI)*

In recent years, the emission of carbon dioxide is one of the hottest topics of the maritime industry. Therefore, as result of comprehensive studies on energy efficiency and GHG emissions, EEDI was established and adopted in accordance with a framework for reduction $CO_2$ emissions from international shipping by IMO. The EEDI is an index of the greenhouse gas emissions from ships, based on data from the ships' design. The index is calculated for new ships of 400 GT and over (IMO, 2011). The principle of EEDI is about measuring $CO_2$ emission (g) per cargo carried (ton mile), so for cargo carriers it is expressed in grams of $CO_2$

per capacity mile of ships. A more energy efficient ship design needs a smaller EEDI value. Figure 4 shows the EEDI calculation formula.

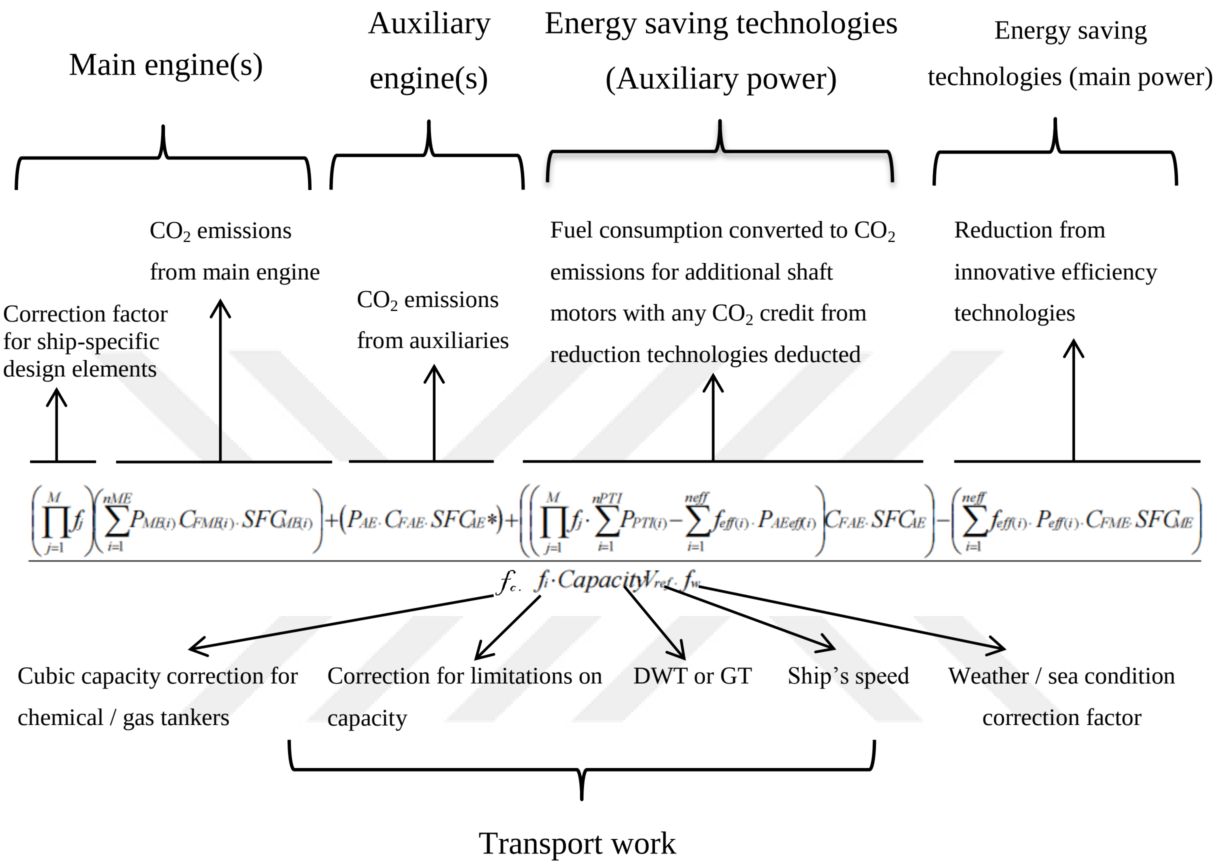



**Figure 4 - EEDI equation (IMO, 2009d)**

That can be demonstrated by the following simplified formula:

$$EEDI = \frac{CO_2\ emission}{transport\ work}$$

Some examples of the energy saving technologies may be waste heat recovery systems, use of wind power or solar power. The formulation of the EEDI is detailed within the 2012 guidelines on the Method of Calculation of the Attained EEDI for new ships (IMO, 2012a). A list of parameters, which can affect the EEDI, is in Appendix 1.

As a conclusion, the index was adopted in 2011 and entered into force in 2013 for new ships. The expectation from the implementation of index is that annually 45 and 50 million tonnes of $CO_2$ will be removed from the atmosphere by 2020, and the target for 2030, $CO_2$ reduction will be between 180 and 240 million tonnes (IMO, 2012b).

#### 2.3.1.2. ***Ship's Energy Efficiency Management Plan***

A SEEMP is required by regulation 22 of Annex VI of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). A SEEMP is an approach to monitor ship and fleet efficiency performance over time and also provides some options to be considered while seeking to optimize the performance of the ship (IMO, 2012a). The SEEMP is mandatory for all ships in operation over 400 GT since the 1$^{st}$ of January 2013.

Lloyd's Register (2012) separates energy efficiency measures and practices, and also notes that a small number of measures are ideal for the most effective SEEMPs to have the greatest impact on increasing energy efficiency. Energy efficiency measures and practices include:

- Fuel efficient operations
- Optimised ship handling
- Hull and propulsion
- Machinery and equipment
- Cargo handling optimisation
- Energy conversation and awareness

A sample form of SEEMP can be found in appendix 2.

#### 2.3.1.3. ***Energy Efficiency Operational Indicator (EEOI)***

As mentioned before, the SEEMP provides an approach for monitoring the ship and measuring fleet efficiency performance. In this context, the EEOI is a monitoring tool and enables operators to measure the fuel consumption of ships in operation and to calculate the impact of any changes in operation, for example: more frequent propeller cleaning, improved voyage planning etc. The EEOI can be calculated by the following formula:

$$\text{EEOI} = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D}$$

$$\text{Average EEOI} = \frac{\sum_i \sum_j (FC_{ij} \times C_{Fj})}{\sum_i (m_{cargo,i} \times D_i)}$$

**Figure 5 - EEOI equation (IMO, 2009b)**

### *2.3.2. Market Based Measures (MBMs)*

In addition to the technical and operational measures, IMO also adopted market based measures (MBMs) to control and reduce $CO_2$ emissions from international shipping. Because, according to Marine Environment Protection Committee, the technical and operational measures was not sufficient to GHG emissions from international shipping (IMO, 2009c). MBMs offer two purposes;

- providing an economic encouragement for the maritime industry to reduce its fuel consumption by investing in more fuel efficient ships and technologies and to operate ships in a more energy efficient-technic; and

- Offsetting in other sectors of growing ship emissions.

## 2.4. Comments

The efficiency of ships has become a popular topic in the maritime industry in recent years. Because, the energy efficiency has two main advantages which are environmental and economic. In this sense, environment and economy could be considered popular topics in the community.

When the climate change was discovered by research, climate scientists started to study the effects of increased temperatures and atmospheric carbon dioxide on the world's oceans and weather patterns. As a result of these unfortunate findings of studies, engineers in nearly every sector, which contributes GHG emissions, have started to seek ways to produce cleaner energy and new efficient methods. Additionally, social scientists, policy experts and lawyers studied to find policies and legal tools to reduce GHG emissions and increase efficiency. At this point, IMO studies oriented to reduce GHG emissions from ships. It can be considered that IMO approached the problem by assessing environmental and economic advantages of the energy efficiency.

Another aforementioned advantage of the energy efficiency is economic. At the first stage, it can be thought that there is no economic advantage, even a disadvantage in fact, in the adaptation of new technologies order to reach efficiency. However, in the long term, the energy efficiency will bring economic advantage if a great energy efficiency strategy would be implemented. On the other hand, increasing fuel prices and the peak oil prices reached in the middle of 2008 were an awakening for the efficiency and the clean technology market. IMO's studies to reduce GHG emissions from ships had been started before the fuel prices problem appeared in the middle of 2008. However, high fuel prices ensured the sector adaptation and concentration on the energy efficiency together with raising the importance of IMO studies.

## 2.5. Summary

The investigation on the GHG emissions from international shipping was made by IMO and it was realized that of all gas emissions, the most was $CO_2$ emission. This statistic was also seen in global emissions in 2007. In this comparison, $CO_2$ emission from international shipping contributed only 2.7% of total global emissions. Despite there is an emission increase in 2050 scenarios, there is potential of a huge reduction of up to 75% of the emissions by technical and operational measures and known technology, but the limit of this potential is not known because of undiscovered technology and methods.

In this process, several studies mention the importance of energy. It is noted that the implementations to promote energy efficiency are continued from construction stage to scrapping in shipping sector. From start to finish, achieving absolute efficiency is related to saving energy, and then adopting new technologies to reduce emissions. Therefore, IMO adopted a few measures to regulate emissions to reduce emissions and ensure more efficient ships.

Also, in this chapter, the importance of the regulations is mentioned. One of the most important is MARPOL which is designed to prevent pollutions of seas. With the increasing effect of climate change, energy efficiency and GHG emissions began to be hot topic in maritime sector. Within this context, IMO studies on GHG emissions are accelerated and policy options are published for reduction of emissions. The following policies can be drawn with respect to options being discussed within IMO; EEDI, SEEMP, EEOI, MBMs.

EEDI provides a mandatory limit for new ships to improve the design efficiency. Therefore, it can be regarded as one of the most important aspects, because it brings exact results to build more efficient ships and reduce GHG emissions in design stage.

SEEMP provides a feasible approach to raise awareness of cost-effective measures to reduce emissions from ships in service. Typically, SEEMP is about generating a great voyage and operation plan. It is not formulation based like EEDI and EEOI.

Another measure was published by IMO is EEOI. EEOI can provide a great incentive to reduce emissions from ships in service. Although, it incentivizes technical and operational measures, it is more useful for ensuring operational efficiency. In addition to these, MBMs are used to control and reduce emissions.

Consequently, thanks to technologies and operational strategies, the reduction from ships can be up to three quarters. The operational approach could reduce emissions from ships by 50%. At this point, fleet management, voyage optimization and energy management will be our most and explicitly mentioned topics, and so far this study has tried to explain energy efficiency, GHG emissions and regulations. The following sections will try to discuss the implementation of operational solutions to reduce emissions and to reveal more efficient ships.

# 3. TECHNOLOGIES AND SOLUTIONS

In the previous chapter, it is described that ships are emitting a significant amount of emissions of greenhouse gases and as a result the maritime sector is becoming one of the most important sources of air pollution. However, it was shown in the previous chapter, there is a great potential for reduction of emissions from ships through international regulations. This chapter begins by laying out the technological and operational dimensions of the research, and looks at how these dimensions can affect emissions from ships.

Almost all emissions from ships are reduced when less energy is consumed. When looking with this perspective at the relationship between emission and efficiency, it is very easy to understand this relationship. IMO refers to options for reducing emissions from shipping. In general terms, the options can be categorised in the following four sections (Buhaug et al., 2009).

- Improving energy efficiency, meaning doing more work with the same energy. This can be applied in terms of design and operation of ships.
- Usage of renewable energy sources like wind and sun.
- Usage of low-carbon or zero-carbon contained fuels, e.g. bio fuels and natural gas.
- Adaptation of new technologies to reduce emissions, e.g. achieving reduction of emissions through chemical, capture and storage.

In simple terms, the energy efficiency can be described as efficient energy use, and the goal of the energy efficiency is to reduce the amount of energy usage for the procurement of the same products or services. A classic example of this is that installing fluorescent lights or natural skylights reduces the amount of energy required to attain the same level of illumination compared with using traditional incandescent light bulbs. In this example, the option for improving energy efficiency is fluorescent lights or natural skylights. On the other hand, there are several options for improving energy efficiency in the maritime industry. In the following table, these options are categorized such as design and operation.

| Options for Improving Energy Efficiency | |
|---|---|
| Design | Operation |
| Concept, design, speed and capability | Fleet management, logistics and incentives |
| Hull and superstructure | Voyage optimization |
| Power and propulsion systems | Energy Management |

**Table 3 – Options for Improving Energy Efficiency (IMO, 2009d)**

As a general approach, measures to reduce the greenhouse gas emissions of ships can be divided into three categories.

- Technical measures
- Alternative fuels and power sources
- Operational measures

The Second IMO GHG Study, in 2009, notes already existing technical measures, which are very important for further improvements of energy efficiency, and provides more efficient engines and propulsion systems, improved hull designs and larger ships. Also, the study notes operational measures such as lower speed, voyage optimization, and energy management, and renewable energy sources are just as important as technical and design-based technologies. Generally, in the sector, the technical and design based measures are put in the centre of focus, but the main weakness of the sector is the failure to address how the operational solutions are used very actively. Therefore, in the following section, existing technical and design-based technologies will be described briefly, and then the chapter will focus on operational measures that can achieve noteworthy reductions in fuel consumption.

## 3.1. Existing Technical and Design-Based Technologies

This section describes existing technical and design-based measures such as engine adaptations, and the use of coatings. When technical measures are compared to operational measures investment costs are relatively high, but on the other hand, the emission reductions have potential to be high. In general, retrofitting is more costly compared to applying technical measures in the design and building phase of a ship.

Generally, the technical measures can be separated into three subgroups: hull related technical measures, propeller related technical measures and engine related technical measures. Each title can be described with the aid of some examples of both design and retrofit measures. Optimal functioning of the propeller, engine and hull are closely linked to each other. Therefore, optimisation of hull, engine and propeller are best carried out at the same time (CNSS, 2013). The average recycling age of ships is 27.7 between 1990 and 2006 (Mikelis, 2007). In this long lifetime ships, these technologies play an important role to actual emission reductions. However, the effects of some measures can be seen in the long term while some of them can be seen in the short term. It is related to data availability, data collection methods, and their right implementation on board of ships.

### *3.1.1. The hull related measures*

This measure type is one of the technical measures. Ll and Zhao (2011) describe that reducing total resistance of ships is one of the most effective and well-known methods for reducing fuel consumption. With this design, new hull form techniques are developed. The following table describes the hull related techniques with the main lines.

| Category | Measure | Ship Type | Reduction | Payback Time |
|---|---|---|---|---|
| Hull | Shape of the hull to reduce air and wave resistance | All ship types | Max. 9% | > 15 years |
| | Reducing the weight of the hull | All ship types | 7% | < 1 year |
| | Hull coatings | All ship types | 5-9% | < 1 year |
| | Air lubrication | All ship types | 5-15% | |

**Table 4 – Measures related to the hull (CNSS, 2013)**

### *3.1.2. The propeller related measures*

This is another type of the technical measures. In order to reduce resistance and to make optimal use of the energy, the propeller of a ship can be optimised by propeller optimisation and propeller upgrade technics. The following table these techniques.

| Category | Measure | Ship Type | Reduction | Payback Time |
|---|---|---|---|---|
| Propeller | Change of rudder profile and propeller | Tanker, container RoRo | 2.6 % | Medium |
| | Upgrading the tip of the propeller | Tankers | 0.5-3% | Medium |
| | Propeller boss cap with fins | All ship types | 1-3% | |
| | Optimisation of propeller blades | All ship types | <2% | Very short |
| | Contra-rotating propellers | Single-screw ships | 3-6% | |
| | Free rotating vane wheel/Grim wheel | Cargo ships | 10% | |
| | Ducted propeller | Tankers, bulk carriers, tugs offshore supply and service vessels | 5-20% (average 10) | |
| | Pre-swirl devices | All single-screw ships | 1-9% | |
| | Post-swirl devices | All new ships | 1-9% | |
| | Integrated propeller and rudder units | Cargo vessels, RoPax vessels and container vessels operating at relatively high speed | | |
| | Wing thrusters | RoRo and ferries | <10% | Medium |
| | Pulling thrusters | RoRo and ferries | <10% | Medium |

**Table 5 – Measures related to the propeller (CNSS, 2013)**

### *3.1.3. The engine related measures*

Another technical measure is the engine related measures that focus on engine upgrade by tuning. The known engine related measures are listed below.

| Category | Measure | Ship Type | Reduction | Payback Time |
|---|---|---|---|---|
| Engine | Common rail technology | All ship types using diesel-mechanical engines | 0.1%-0.5% | Short |
| | Waste heat recovery | Ships with a high production of waste heat | 8-10% | |
| | Diesel electric propulsion system | RoRo, ferries cruise ships | <20% | Medium |
| | De-rating the engine | All ship types | n.a. | n.a. |

**Table 6 – Measures related to the engine (CNSS, 2013)**

## 3.2. Alternative Fuels and Power Sources to Oil

In fact, all emissions from ships are fuel-sourced and the amount of emissions depends on the type of fuel. IMO categorizes fuel types as coal, oil, gas, nuclear, biomass, and other renewable sources, but today the most and also only significant energy source is oil for international shipping (IMO, 2009d). In this context, this section describes alternative fuels and power sources, and their contribution compared to oil in order to augment efficient green ships. The shipping industry explores a number of alternative fuel sources to help reduce $CO_2$ emissions (ICS, 2013). In sources, these alternatives are collected under five titles as renewable energy, fuel cells, nuclear propulsion, liquid natural gas (LNG), and biofuels (Surplus, 2011, Calleya et al., 2011a, Ong and Olcer, 2011). As aforementioned, the emission from the global maritime industry is 3.3% of global emissions and this figure tends to increase significantly as suitable solutions are not produced. The alternative fuel and power sources could be appropriate solutions for this problem.

### *3.2.1. Renewable Energy Sources*

The renewable energies for ships can be generated on board, (wind, solar, and ship-motion-generated energy) and on shore, as hydrogen (IMO, 2009d). The renewable energy sources make up a significant proportion of total energy consumption in the global usage. Solely, at the present time, the renewable energy sources for ships cannot used as an alternative, they can only be used for energy saving.

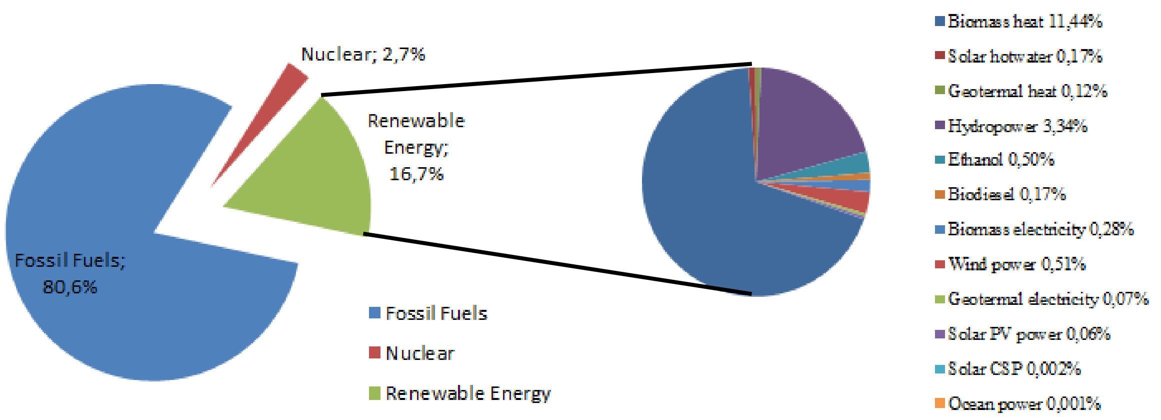



**Figure 6 - Total World Energy Consumption by Source (2010)**

The above pie chart shows the percentage distribution of renewable energy sources is 16.7% of total world energy consumption. However, it should be considered that GHG emissions of fossil fuels which comprise 80.6% could be decreased drastically by suitable adaptation of the renewable energy to GHG emitted vehicles, firms and other things.

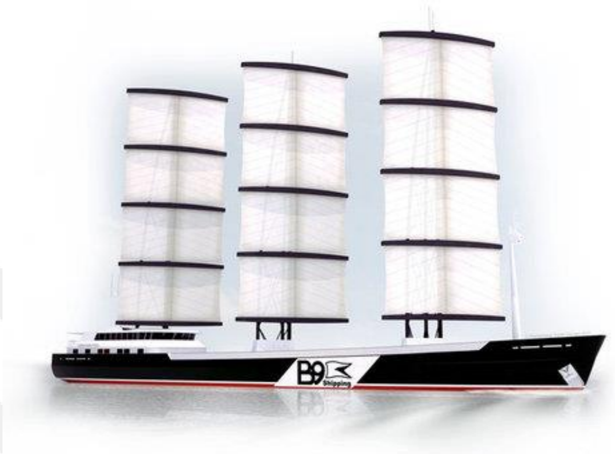


**Figure 7 – B9 Shipping / Flagships of the Future   Source:B9 Shipping (B9, 2013)**

When looked at from a maritime perspective, ships could be adopted to a few renewable energy sources which are wind and solar sourced energy. Implementations of these energies can be seen at figures 7 and 8.


**Figure 8 – Progress of green shipping     Source: Eco Marine Power**

The future expectation regarding renewable energies, which are used by ships, is to create zero or low-carbon emitted ships thanks to these more environmentalist energy sources. It can be seen from above figure 7 and figure 8 that wind and solar sources have begun to be adapted to ships as separately and in combination. Another implementation of wind power is skysails that can ensure energy saving between 30% and 50%. This would depend on wind force, wind direction and ship size and weight.

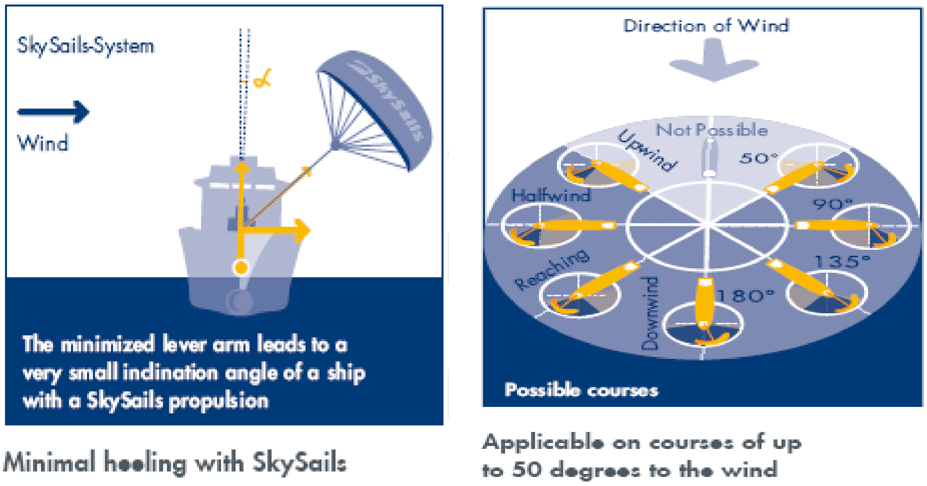



**Figure 9 – Sky Sails- System and Direction of Wind Source: Sky Sails (2008)**

### *3.2.2. Fuel cells*

Fuel cells are not real alternative fuel source to mitigate carbon emissions from ships. It can be described as a contributing power source. Because, when compared with other fuels, its power density is lower and it cannot be applied to merchant vessels (Clelland et al., 2011). For this reason, its application generally has been carried out on river boats, using pure hydrogen as fuel. Some known fuel cell types are AFC, DMFC, PEMFC, and SOFC.

### *3.2.3. Nuclear*

According to IMO GHG Study, installing a nuclear reactor on board is not suitable because of environmental, political, security, and commercial reasons (IMO, 2009d). However, in terms of emissions, nuclear energy has advantages with its zero emission during ship operation, although there are security, reliability and socio-economic issues.

### *3.2.4. Liquid Natural Gas (LNG)*

LNG is predicted as the most potential alternative to fossil fuels because the natural gas is one of the most plausible solutions to reduce gas emission from ships, and it is also preferable because of its low GHG emissions, high energy density and price when compared to oil (Calleya et al., 2011a). However, like any alternative fuel, natural gas has a disadvantage that is about the implementation of natural gas are safe storage, low storage density, supply and availability in ports and its first configuration on board. Presently, investments on LNG fuelled ships are increasing dramatically; the least significant instance is that the world's fastest ship is LNG fuelled. It is constructed at Incat Shipyard in Tasmania (Blikom, 2013).

**Figure 10 - Two rockets and a passenger lounge brought to you by Incat, Tasmania Source: DNV, 2013**

### *3.2.5. Bio Fuels*

Another possible alternative fuel is biofuels made from sugar, starch, vegetable oil or animal fats by using conventional methods (IMO, 2009d). Biofuel is predominantly obtained from biomass and bio waste to use for any purpose. Previous research findings into biofuels that concluded biodiesel can reduce net $CO_2$ emission from ships by 78% compared to petroleum diesel (Ong and Olcer, 2011).

## 3.3. Operational Measures

The whole life cycle of a ship can be divided into four categories, and these categories are: processing and transportation of materials required for ship building, ship building, and ship operation and scrapping. As an example, the following figure shows the carbon emission statistics of an 180,000 DWT bulk carrier during her life cycle.

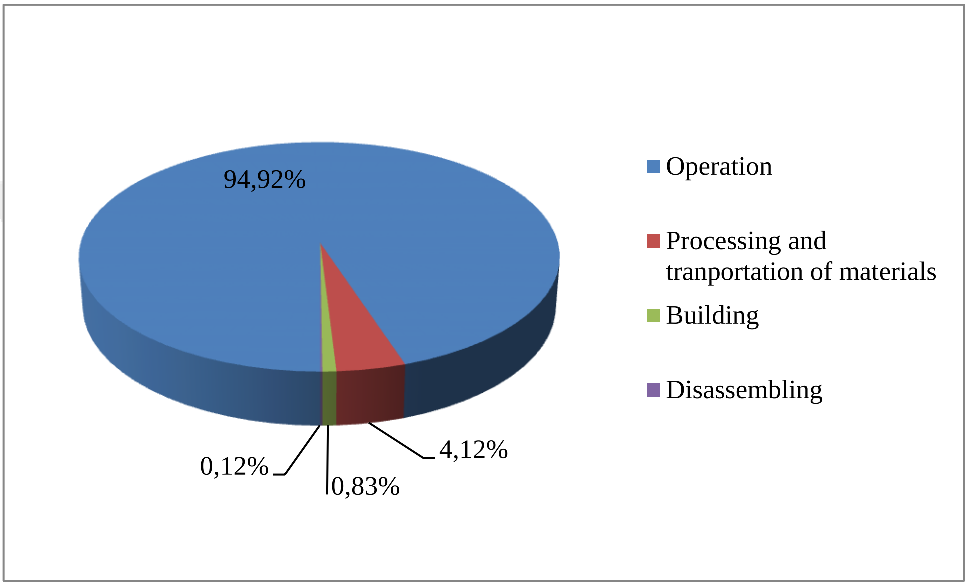



**Figure 11 – Carbon emissions statistics during the whole life cycle of a ship Source: (LI and Zhao, 2011)**

When looked at the above pie chart, it can be seen that the operation stage covers almost the whole of $CO_2$ emission from ships. Therefore, the operational stage is very important for more and more energy efficient ships. Additional to the above reason, besides operational solutions, the implementation of every solutions are related to operational decisions, but some technologies, which are adapted to ships at construction stage, are excluded. According to the MEPC (IMO, 2009d), saving energy at operational stage is related to the development of the EEOI and SEMP, and IMO's approach to operational methods to reduce gas emissions from international ships covers the following titles.

- Fleet management, logistics and incentives
- Voyage optimization
- Energy management

The following measures are marvellous examples for operational solutions to ensure ship energy efficiency measures (Sener, 2013). These can be defined as subtitles of above three titles.

- Passage planning,
- Route setting based on the weather and sea conditions,
- Speed optimization,
- Just in time,
- Optimum use of rudder and heading control systems (Auto Pilots),
- Propeller and hull maintenance,
- Main and auxiliary engine maintenance and performance,
- Type of fuel and management,
- Heating operation of fuel and cargo.

The key point here, "Better planning at the design stage may lead to a higher potential for reduction at the operational stage." (Buhaug et al., 2009)

### *3.3.1. Fleet management, logistics and incentives*

The fleet management and logistics lead to reduce fuel consumption and gas emissions from ships. However, the fleet management and logistics could be more useful when more efficient and suitable strategy and methods are applied for different shipping activities. They constitute a part of the operational stage of shipping. Yet, when mentioned about the fleet management; technical management, crew management and commercial management of this fleet should be considered.

Morgan and Katsoulakos (2010) assert that a fleet contains different types of ships (e.g. tankers and bulkers) and can be divided into geographical areas (e.g. Mediterranean fleet, Atlantic fleet etc.). Generally, using larger ships can be thought that they tend to be more efficient, but in practice, this situation cannot be correct every time. The important point is that energy efficiency is closely linked to using the right ships in a transport system. In this situation, two scenarios can be considered; the first is that using large ships could be more useful to reduce energy consumption if there is enough cargo for large ships. For example;

using larger ships in the container sector can be efficient in the main shipping leg if they are used between two hub ports. The second scenario is that door-to-door logistics reduces larger ships efficiency, so the distribution of cargoes should be done by smaller ships to reach required efficiency from ships, and also from the total shipment of freight from the manufacturer to end consumer. Typically, in order to increase efficiency of ships, it can be said that the main strategy should be larger ships to longer routes and deepest ports, and smaller ships to shorter routes, and also self-unloaded ships to shorter routes to reduce waiting time at ports (Buxton, 2012).

The following two figures show that shipping network without (above) and with (below) transhipment (Lloyd et al., 2011). The following figures show an excellent example of fleet management and logistics strategy. Figure 12 demonstrates the shipping network without a hub port between 12 spoke ports and it can be seen that there are 36 different routes, which can rise according to the number of ports and the applied strategy for existed port in the figure, between 12 ports. It means that there is a need for more ships, more crews and it causes more fuel consumption and to appear light leg in some routes, and it can be clearly seen that it causes inefficient shipping activities.

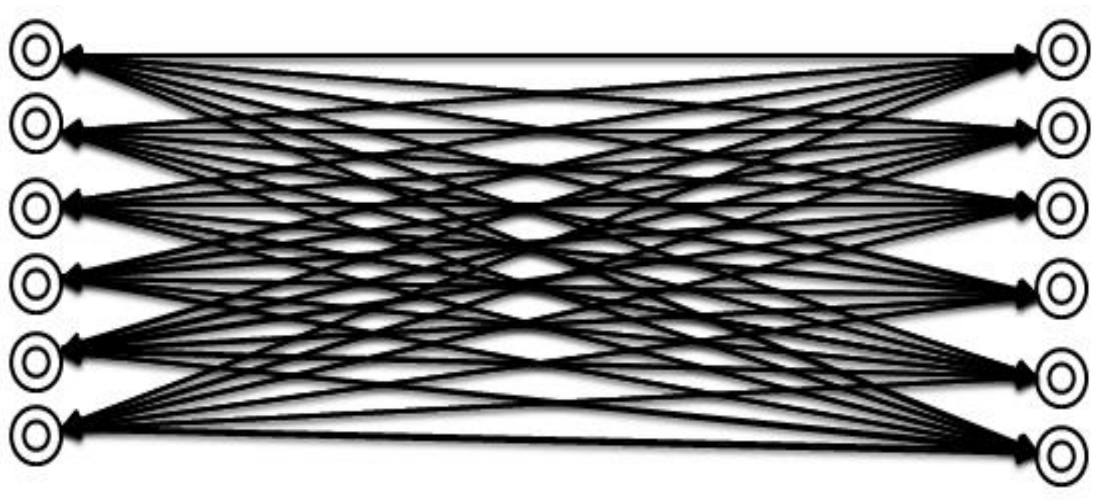


**Figure 12 –Shipping network without transhipment**

When looking at Figure 13, it can be seen that the number of networks between ports are decreased by using a hub port for transhipment of cargoes which are coming from different ports. At this system, there are just 12 routes, and less ships, fewer crews could be sufficient to manage hub-port system. It means that more efficient fleet and more efficient single ship related to fleet efficiency. Also, energy efficiency could be high for a small ship for strategy in Figure 13, because small ships can access more ports and cargoes in this method. However, applying to large ships could be more available for the second strategy. Particularly, this strategy can be more useful for the container sector.

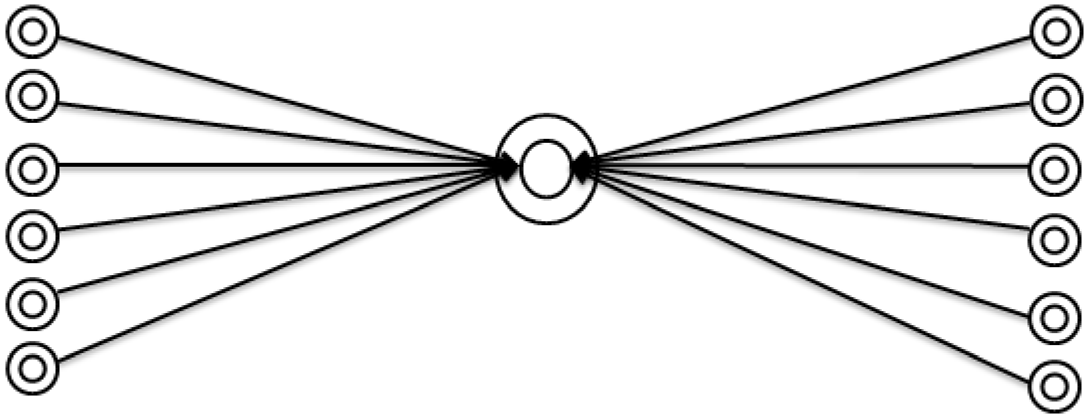


**Figure 13 – Shipping network with transhipment**

A key factor in the fleet management and logistics is slow steaming which is one of the most important methods to reduce emissions, but in this situation, more ships will appear to be necessary to carry the same amount of cargo because of a decrease of ton-mile efficiency. However, the application of slow steaming can affect efficiency of ships when freight rates are low and fuel prices are high (Buhaug et al., 2009). A good example is shown below to understand the importance of the slow steaming effect to energy consumption from Lloyd's Register sources (Lloyd's, 2008).

A 6800-TEU Container Ship,
Route: Middle East to Tokyo
Sailing time: 10.5 days at 25 knots and Fuel Consumption: 192 tonnes/day of HFO
Total fuel consumption at 25 knots: 10.5 day x 192 tonnes/day
= 2016 tonnes of HFO
When speed is reduced by 3 knots,

Sailing time: 11.93 days at 22 knots and Fuel Consumption: 131 tonnes/day of HFO

Total fuel consumption at 22 knots: 11.93 day x 131 tonnes/day

= 1,562.83 tonnes of HFO

Fuel saving from speed reducing = 2016 – 1,562.83

= 453.17 tonnes of HFO

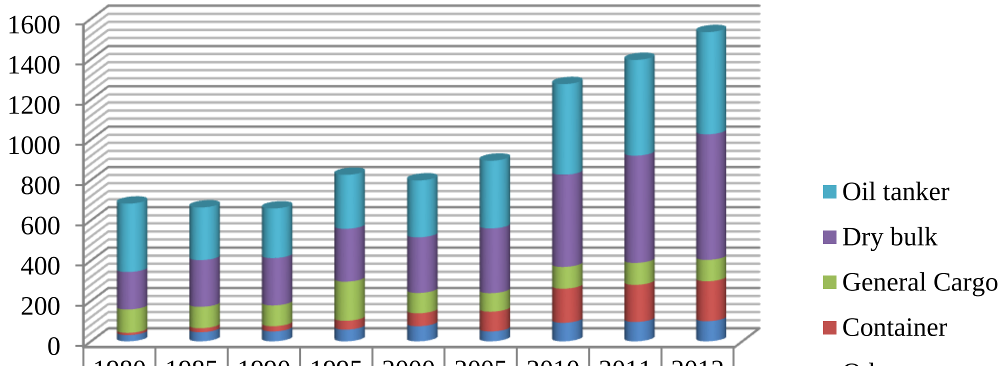
Economic saving = 592 $/tonne (bunkerworld, 2013) x 453.17 tonnes

≈ $282,000

In above example, current fuel price is used.

As seen from example, huge amount of money can be saved by reducing speed of ships. The above amount, which is $282,000, is just for one voyage. When considering $CO_2$ emission value, it is another huge saving from 3-knot speed reduction, and today it generates shipping sector's interest area. Also, according to A.P. Moller Maersk Group statistics, around 2 million tonnes of carbon dioxide was saved by Maersk Line thanks to slow steaming (Jorgensen, 2011). Another story about slow steaming, by taking advantage of Maersk Line's large experience in this field, Maersk Tanker reduces their VLCC tanker speeds to 8,5 knots, and by this way, they saved $400,000 on the ballast leg for a standard voyage (Skou, 2013). Soren Skou, who is Maersk Tanker CEO, says in a TradeWinds interview "What it effectively means is that on an Arabian Gulf to Japan or China voyage the fuel savings will pay for the additional days. It doesn't really cost you to extend the time the voyage takes and you are doing something good for the environment." (TradeWinds, 2013).

Other key points for logistics are port organization, traffic management and control systems. There are several impacts to increase port based ship efficiency. Some of these are the queue management system, cargo handling facilities, berthing and mooring facilities. The queue management system can play a significant role to increase efficiency, e.g. First in (Buhaug et al., 2009). The world fleet size distribution by vessel types is shown in the graphic below. We can see the importance of port organization, traffic management and control systems by using Figure 14, because the world fleet size is dramatically growing year by year. While the world fleet size is increasing, the importance of port based logistics strategies are increasing to be able to ensure required efficiency level.




| | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|
| Oil tanker | 339 | 261 | 246 | 268 | 282 | 336 | 450 | 475 | 507 |
| Dry bulk | 186 | 232 | 235 | 262 | 276 | 321 | 457 | 532 | 623 |
| General Cargo | 116 | 106 | 103 | 194 | 101 | 92 | 108 | 109 | 106 |
| Container | 11 | 20 | 26 | 44 | 64 | 98 | 169 | 184 | 198 |
| Other | 31 | 45 | 49 | 58 | 75 | 49 | 92 | 96 | 100 |

**Figure 14 – World fleet by principal vessel types (millions of DWT) Source: UNCTAD (2012)**

In this context, subject to the increasing importance of these factors, co-operation of parties in the sector can create opportunities to optimize and improve operational efficiency (IMO, 2009d). For efficient fleet management and logistics activities, the co-operation and to apply third parties can have unforeseeable impacts. Therefore, the management of a fleet should be made by applying to expert companies in their areas. For example;

Technical needs of a ship: a technical operator
Commercial activities: an expert company on economy
More efficient operational activities: a different expert company than the commercial operator
Logistics activities: an expert logistics companies should be applied. Thus, the general efficiency could be ensured with together cost reductions.

Also, incentives can cause inefficient operations because of economic concerns. An example from IMO GHG Study 2009 is demurrage, "If the port is able to handle the ship, the ship operator can take on a new cargo; if not, the ship operator is compensated by the demurrage. Often the demurrage rate is higher than the extra fuel cost and then, in both cases, the incentive for the ship operator is to sail at high speed to arrive as early as possible."

The following parties in shipping that affects transport efficiency directly or indirectly.

- Owner
- Charterer
- Multi-modal transport operators (MTOs)
- Shipper and receiver of the goods
- Cargo buyer/seller (the original source of the transport demand)
- Agents/brokers
- Port authorities
- Terminal operators and
- Others (shipping agents, stevedores, tug operators, pilots, bunker suppliers and other service providers).

### *3.3.2. Voyage Optimization*

Voyage optimization is another effective operational measure to reduce gas emission and to increase efficiency of ships. Generally speaking, the voyage optimization can be described as the optimization of ship operation. Therefore, voyage optimization can be achieved by people who are directly in the loop such as ship operator and the master (Buhaug et al., 2009). However, according to IMO GHG Study (2009d), there are several constraints, which are imposed by logistics, scheduling, contractual arrangements and others, such as:

- Weather routing; depending to weather conditions, to select optimal route can generate more optimum voyages. The advantages of weather routing are time and cost reductions and increased safety if heavy weather routes is not preferred (NIMA, 2008). Shao and Zhou (2011) note that the optimum route depends on the following three aspects .
    1. The accuracy of the prediction of ship’s hydrodynamic behaviour under different weather conditions.
    2. The accuracy of weather forecasts.
    3. The capability and practicability of the optimisation algorithm used.

- Just-in-time arrival; for this, contractual arrangements and incentives like penalties and demurrage are important. However, tides, queues and arrival windows should be considered for optimum voyage plan by ensuring just-in-time (Buhaug et al., 2009).
- Ballast optimization; it is another constraint for voyage optimization. The main approach for this to avoid from unnecessary ballast. It can also affect crew safety and comfort.
- Trim optimization; the correct trim can make a positive impact on ship resistance and speed and this affects hydrodynamic ship efficiency. It is required that forward draft is lower than aft draft for optimum trim measure, but it can change by ship size, loaded cargo amount and ship speed. An example of trim table to assist during voyage planning.

| | Speed | 18 knots | | |
|---|---|---|---|---|
| | Trim | - 1,0 m | 0,0 m | 1,0 m |
| Draft | 9.0 m | Good +0.0% | Good +0.9% | Fair +1.5% |
| | 7.0 m | Good +0.0% | Fair +1.3% | Avoid +3.7% |

**Table 7 - Example of trim table to assist during voyage planning Source: DNV**

The required optimum trim can be seen at the below Figure 15. It gives optimal trim value for a bulk carrier at 16 knots by using trim optimisation tool which was developed by DNV.

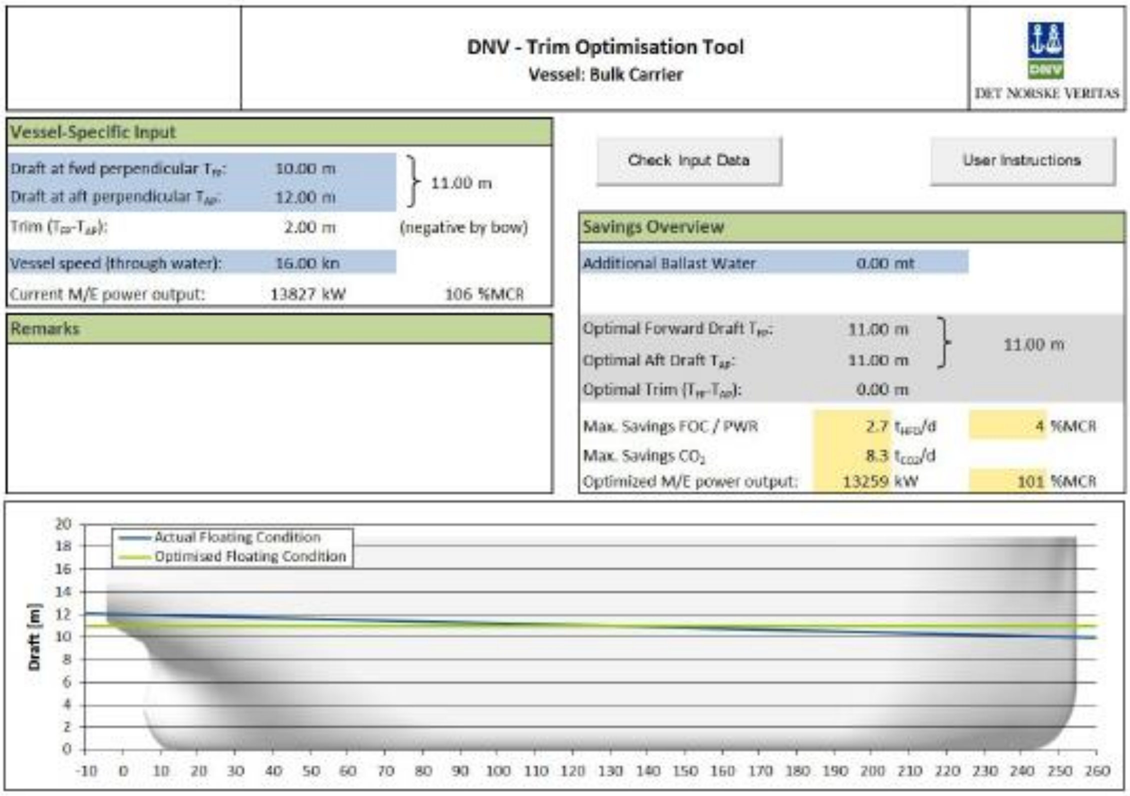



**Figure 15 – Example from the on board trim tool Source: DNV**

As a summary, there is a great potential to increase efficiency from ships by ensuring optimum voyage planning. However, it depends on how ships are operated, which can be changed related to economic drivers and other variables.

| | Current | Potential |
|---|---|---|
| Trim and ballast optimization | 0-1% | Higher figures are relevant for specific ship types. |
| Weather routing | N.A. | N.A. |
| Just-in-time arrival | 1-5% | Economic considerations cause inefficient operational arrivals |

**Table 8 – Potential savings by voyage optimization constraints**

In order to reach optimal voyage performance, several types of weather routeing systems, technical support systems, performance monitoring systems and other systems can be used.

The key point about using and understanding of these systems is the skill and motivation of the crew.

### *3.3.3. Energy Management*

Energy management means that planning and operation of energy and to ensure maximum benefit with minimum energy. A good energy management can bring several advantages to any sector. When considered in this context, the energy management can play a vital role to meet environmental and economic requirements of the maritime sector. Because, the power is one of most important needs -maybe first- for propulsion, crew needs and various ancillary systems e.g. cooling-water pumps, ventilation fans, control and navigation system and more. Also, ships need to high power for transverse thrusters to manoeuvre at low speed, although they are used for short periods. The most power needed ships are passenger ferries and cruise ships for passenger accommodation and comfort (IMO, 2009d). Another power need on board is that for cooling and/or heating to maintain cargo quality.

Aforementioned previous paragraph, ships need high power for various things, and the power must be supplied by main engine, auxiliary engines, boilers, generators by burning generally fossil fuels. It is possible to reduce energy consumption thanks to a great energy management. IMO (2009d) offers energy management related measures that include:

- Avoidance of unnecessary consumption of energy;
- Avoidance of parallel operation of electrical generators;
- Optimization of steam plant (tankers);
- Optimization of the fuel clarifier/separator;
- Optimized HVAC (Heating, Ventilation and Air Conditioning) operation on board;
- Cleaning the economizer and other heat exchangers; and
- Detection and repair of leaking steam and compressed-air systems, etc.

It is mentioned about ways for maximum-output of the energy management, but there is a need to important investments in order to use the ways actively. These investments should be made in training and motivating the crew, in monitoring/benchmarking consumption, and in automation and process control technologies such as automatic temperature control, flow control, automatic lights etc.

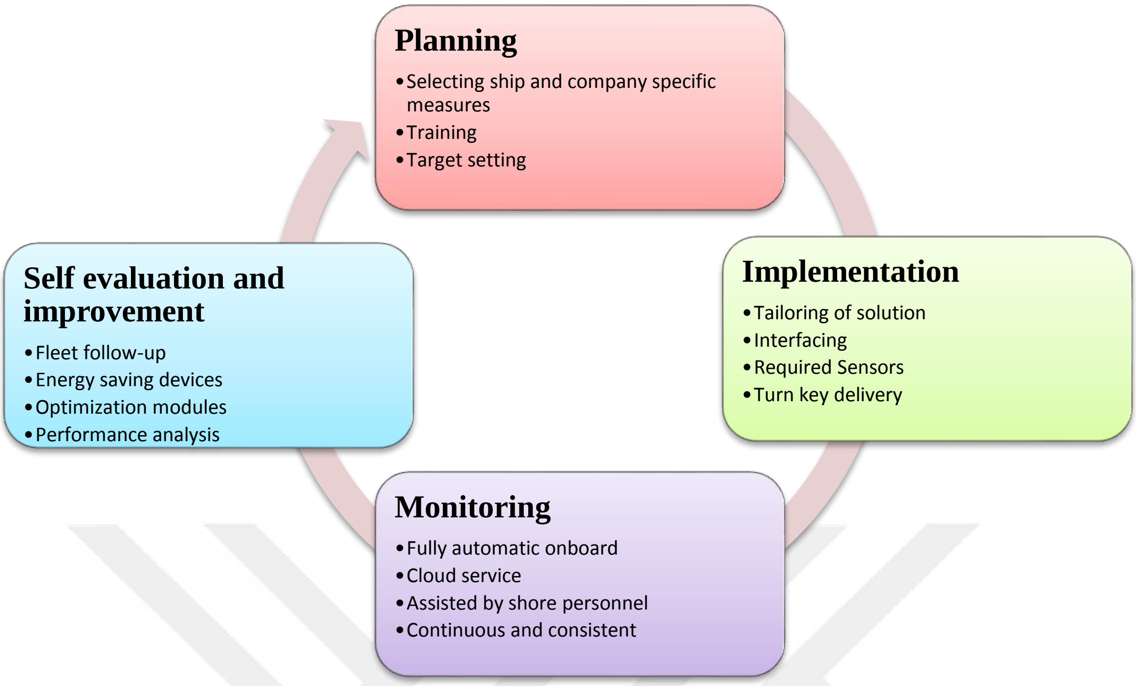



**Figure 16 – SEEMP process**

The assessment of the energy-saving potential of energy-management measures is difficult, because a huge amount saving on auxiliary power can correspond to 1-2% of total consumption of fuel. Therefore, the assessment should be made by viewing total energy picture. While the assessment is making, the SEEMP process, which is given at Figure 16, could be very useful to reduce energy consumption.

Additional to above measures, optimal maintenance of main engines, maintaining a clean hull and propeller are important for fuel efficiency. The tuning of the main engine can make saving of the fuel consumption by 1-2% and the effective and frequent cleaning operation of hull and propeller can amount to a 5% difference in energy requirements (IMO, 2009d).

## 3.4 Comments

Measures are mentioned in this chapter which play a vital role and will continue to play to reduce fuel consumption and emissions from ships. Design or operation measures can reach up to 50% saving of $CO_2$ when these measures implemented on board of ships. However, these measures cannot be considered separately from each other. Because, when the measures are combined, the benefit from emissions can be reach between 25% and 75%.

With the aid of comprehensive studies, three methods, which are EEDI, SEEMP and EEOI, are developed to measure energy efficiency and together with methods the adaptation of new technologies is tried to generate. The table below illustrates that assessment of potential reductions of $CO_2$ emissions from shipping by using known technology and practices.

| | Saving of CO2/tonne-mile | Combined | Combined |
|---|---|---|---|
| **DESIGN (New ships)** | | | |
| Concept, speed and capability | 2% to 50% | | |
| Hull and superstructure | 2% to 20% | | |
| Power and propulsion systems | 5% to 15% | 10% to 50% | |
| Low-carbon fuels | 5% to 15% | | |
| Renewable energy | 1% to 10% | | |
| Exhaust gas CO2 reduction | 0% | | 25% to 75% |
| | | | |
| **Operation (All ships)** | | | |
| Fleet management, logistics & incentives | 5% to 50% | | |
| Voyage optimization | 1% to 10% | 10% to 50% | |
| Energy management | 1% to 10% | | |

**Table 9 – Assessment of potential reductions of $CO_2$ emissions from shipping by using known technology and practices (IMO, 2009d)**

As can be seen from the table, the reduction of $CO_2$ emission from shipping can reach up to 75% when new technologies, which can adapt to ship at construction stage and also some of them can adapt at service stage, combined with operational solutions and strategies. Therefore, as one understood from exist studies, the shipping sector should be considered as a whole in order to obtain more effective results soever it is seperated as technical and operational.

## 3.5. Summary

In this chapter, measures which have a significant place to reduce emissions from ships and create more efficient ships, have been tackled. Options for improving energy efficiency were separated into two titles as design and operation. We tried to describe under three titles with an extra title that is alternative fuels and power sources.

As a first part of chapter, technical and design based technologies are described. These technologies are divided into three subtitles such as measures related to the hull, measures related to the propeller and measures related to the engine. Each of them can be an excellent dissertation topic, but they are only tried to describe with mainlines because of lack of technical background. However, the known measures are listed for each title with ship types, which are suitable for the implementation of measures, their effects to reduce emission by percentage, and their payback times.

We then described which kind of alternative fuel and power sources can affect the development of green ships. These alternative fuel and power sources are tried to explain with aid of five different types which are renewable energy sources (wind, solar and hydrogen which can be used on board of ships among numerous renewable energy sources), fuel cells, nuclear power, liquid natural gas (LNG), and bio fuels. In order to summarize this chapter, Figure 17 could be very helpful to understand alternative fuels effects to reduce GHG emissions from ships. The Figure 17 shows that $CO_2$ emission of different fuels and it can be seen from figure that using B20 is not very encouraging in terms of $CO_2$ emission. Its reason that B20 contains 80% is petroleum diesel, while the other only 20% is biodiesel. When looked LNG, its encouragement is not enough when compared to B100. Therefore, it can be said that pure biodiesel could be the most favourable fuel type.

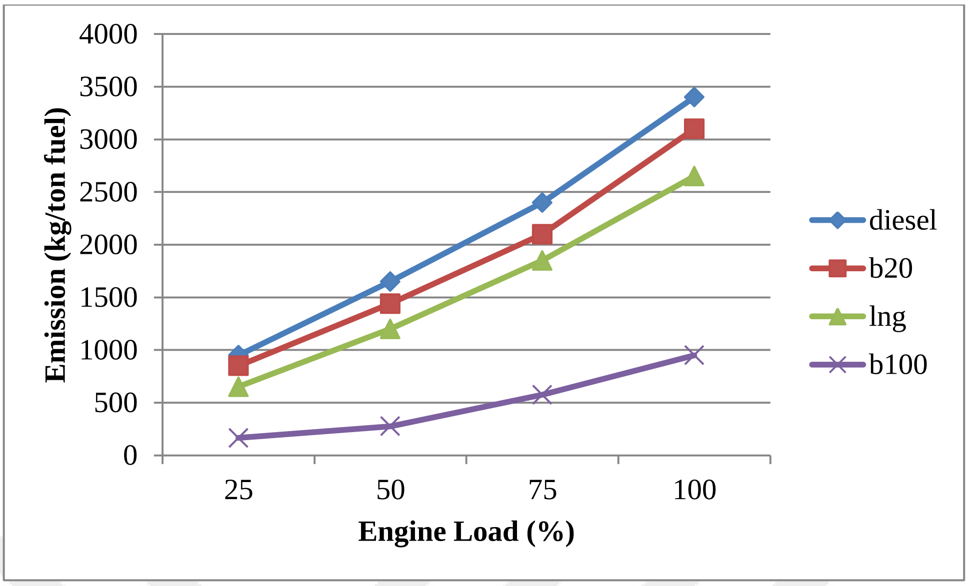



**Figure 17 – $CO_2$ Emissions of Different Fuels Source: (Ong and Olcer, 2011)**

Additional to these fuel types, studies continue to develop fuel cells and nuclear power in order to use in the international shipping, but it will be took time to become usable. Besides, the renewable energies could be used to save energy even if they cannot use as an alternative power. Briefly, biodiesels and LNG could be considered as potential alternative fuels but other alternatives which are fuel cells, nuclear energy, renewable energies such as wind, solar, wave and hydrogen could just be considered as energy saving methods.

As a last part of this chapter, the operational measures are described in details by dividing subcategories like previous parts of chapter. These categories are fleet management, logistics and incentives, voyage optimization and energy management which are very important, because of a huge amount (nearly 95%) of carbon emission occurs in operation stage (Ll and Zhao, 2011). The fleet management, logistics and incentives title is tried to explain with aid of examples that are hub-port strategy and effects of slow steaming to energy efficiency based on fleet management and logistics. Additional to examples, growth in world fleet size makes the operational measures more important especially port based operational measures and it needs more effective co-operation among parties. Another operational measure is described that voyage optimization which is assessed with four constraints; weather routing, just-in-time arrival, ballast optimisation, trim optimisation. The last operational measure is energy management that its assessment is very difficult to see its contribution to energy efficiency, so it tried to explain by using SEEMP process.

# 4. METHODOLOGY

In the maritime sector, there are very transparent relations among companies, and so each company knows other companies' ammunitions and potentials. Specially, in the container sector, this situation is ordinary because rival companies can work together for a route to obtain maximum benefit from the market pie. Therefore, the biggest players in the sector develop some methods like hub port usage, slow steaming and increasing of economy of scale; to reduce cost and energy consumption because of economic reasons and last term energy related regulations. Previous studies show that different companies have measured energy efficiency and fuel saving in a variety of ways that are used to assess their results. Each has its advantages and drawbacks. However, these studies are made by using just one or two companies' statistics, so they do not handle whole of market or all working companies in a specific route. Thus, this paper tried to improve a case study, which can be seen in the following section, in order to deal energy efficiency extensively with the aid of container sector.

The methodology section of this study will aim to give an account of how methods carried out. The case study is used to see the importance of technological and operational measures and covers Far-East/the Mediterranean Sea container trade, routes and container distribution networks in the Mediterranean Sea. Therefore, several data was needed to be able to create a case study in order to make analyse on energy efficiency.

First of all, required data are classified as port related, ship related and route and container trade related energy efficiency. Under these titles, the existing state is searched and analysed. By this means, useful information due to the case study are tried to collect. In this context, applied sources can be arrayed as company and ship research website aggregated and online databases, electronic, journal and magazines' articles, and other works regarding to port, ship and container trade related energy efficiency. Google map, marine traffic, sea-web, netpas, sea-distance were very useful resources to collect port related and ship related data. However, there was immoderate information to make correct analysis for this case study. So, they have been distilled to obtain more realistic outcomes.

Secondly, after the separation of the information, datasets which are related to case study in order to use in it, are generated to be able to analyse easily. The analysis is made with the aid of results from company researches and simple formulations. According to these results, potential locations of hub port are decided, and sizes of container vessel will use in the case study are decided by analysing today's market trends, developing technologies and regulations about energy efficiency.

Lastly, the choosing of most advantageous hub port is made by using the Analytic Hierarchy Process (AHP) which is designed to solve complex problems involving multiple criteria (Saaty, 1980). In this process, obtained data from distance calculator tools (Netpas and Sea-distance.com) are assessed by receiving aid from pairwise comparison scale. In the second part of case study, simple formulations and distance calculator tools are used to assess ship related data (distance, fuel consumption, speed, and route) which had been collected from aforementioned databases like sea-web, company databases, and marine traffic etc. The obtained results from used methods are shown in maps and in tables. Their detailed presentations are added to appendix part which is last part of this study.

As a result, the following case study is created to help understanding the importance of operational measures because they can improve great energy efficient maritime facilities if they use in correct strategy with correct methods.

# 5. CASE STUDY

After the publication of EEDI, SEEMP and EEOI by IMO, they were put in practice on 1st of January 2013. At this date, these measures were started to implement by companies on board vessels as mandatory and the observable results are obtained for new ships thanks to technical and design based measures implementation, but results for other two measures; operational and management based cannot be clear for now. Because, there is a time need to collect the results. When considered 73550 ships, which are 400 GT and above, are in service today, the difficulty of data collection can be understood better (Sea-Web, 2013a). on the other hand, when we looked for EEDI, there are just 845 ships which are categorised as bulkers, tankers, dry cargo/passenger (Sea-Web, 2013b).

In light of this general information and in the context of requirements from sector, this case study will approach to issue from operational and management side and analyse Asia – Mediterranean/Black Sea container lines by using a different port and logistics organizations from present and two different size container ships. The aim of this case study is that to improve more efficient and economic Far – East / the Mediterranean Sea container transport by using a hub port, and also using just one main route to meet container trade volume from Far – East to the Mediterranean Sea with the aid of usage of larger container ships.

## 5.1. Present Situation

Today, a monthly average of container traffic from Asia to the Mediterranean and Black Sea area is 450.000 TEU, the large part of these shipments has been performing from huge Asia Ports like Shanghai, Singapore, Hong Kong, Shenzhen, Busan etc. These ports average of annual container handling amount is over 7.000.000 TEU -accumulative figure with other Asia Ports- (JOC, 2012, Drewry, 2013). When looked the Mediterranean side, the largest container port is Valencia that handled 4.300.000 TEU in 2011.

After general overview to ports, there are 4 main areas in the Mediterranean, these are including;

- West Mediterranean – Spain, France, Morocco, Algeria, Tunisia, Malta, and Italy ports;
- Middle Mediterranean – Libya, Egypt, Italy, Slovenia, Croatia, Montenegro, Greece, Albania and Turkey ports;
- East Mediterranean – Syria, Israel, Lebanon, Turkey, Cyprus, and Egypt ports; and
- Black Sea – Bulgaria, Turkey, Romania, Ukraine, Russia, and Georgia ports.

For these 4 main areas, the biggest container companies generate 4 main lines from Asia to the Mediterranean Sea, and these services are given by container ships that have container capacity between 6.000 and 13.000 TEUs. The main routes do not cover all countries in the Mediterranean area; these routes only cover larger ports in some countries at the area. In order to reach small ports, feeder ships have been already used. The following maps shows four main routes from Far East to the Mediterranean Sea and the following formulas will be used to calculate number of ship in routes and monthly container supply from one side.

$$Number\ of\ Ships = \frac{Days\ per\ round\ trip}{Frequency}$$

$$Monthly\ container\ capacity\ = \frac{Number\ of\ ships\ \times\ Ship\ container\ capacity}{Days\ per\ round\ trip} \times 30$$

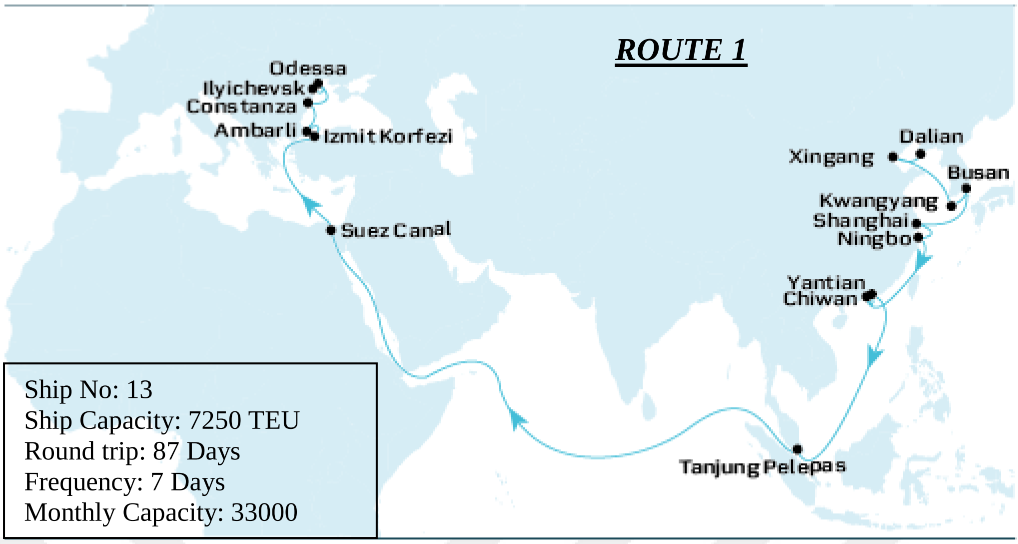



**Figure 18 – Dalian (China) / Ilyichevsk (Ukraine) Container Line Source: Maersk Line**

Route 1 is from Dalian (China) to Ilyichevsk (Ukraine), average 7250-TEU 13 container ships should be used to meet demand with 7-day frequency for voyage that have 86-day per round trip. This route's one-month container capacity from Dalian to Ilyichevsk is about 33.000 TEU from one side.

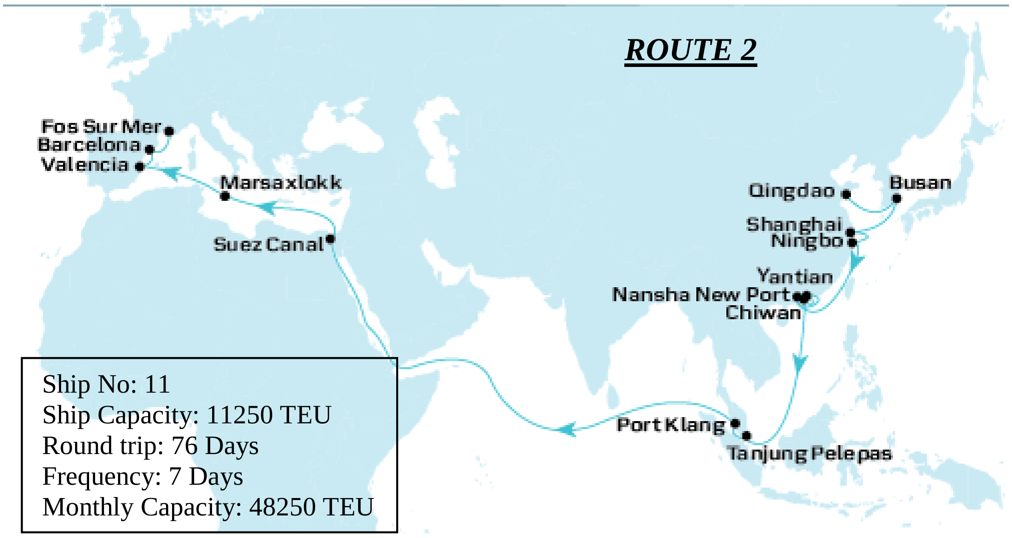



**Figure 19 – Qingdao (China) / Fos-Sur-Mer (France) Container Line Source: Maersk Line**

When we looked, Qingdao (China) to Fos-Sur-Mer (France) route, it needs overall 11250-TEU 11 ships for 7-day frequency voyage and its trip round is 76 days, and monthly container capacity is 48750 TEU.

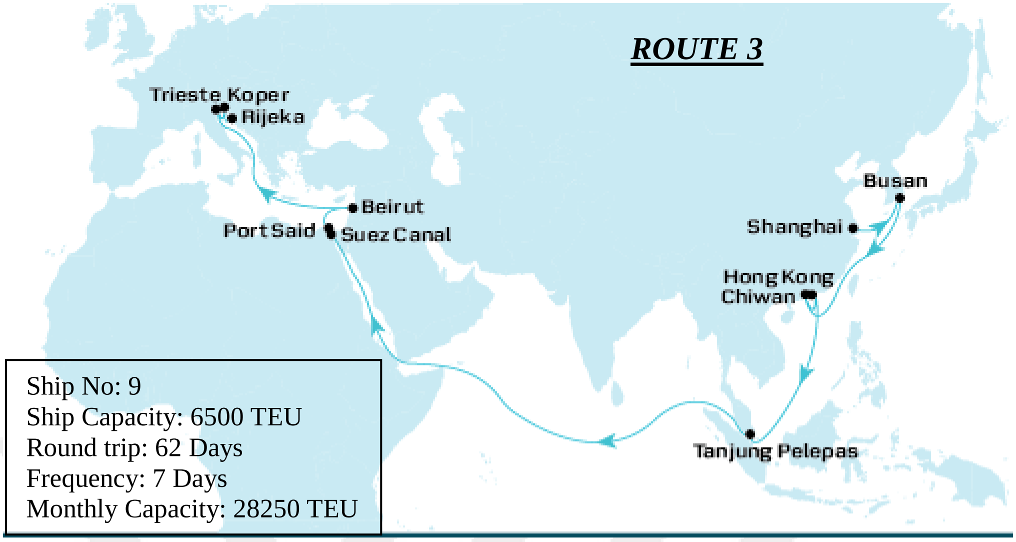



**Figure 20 – Shanghai (China) / Rijeka (Croatia) Container Line Source: Maersk Line**

Another route is Shanghai (China) – Rijeka (Croatia) route, this route needs 6500-TEU 9 ships for 7-day-frequency voyage and it lasts 62 days, and its monthly one-side container capacity is 28250 TEU.

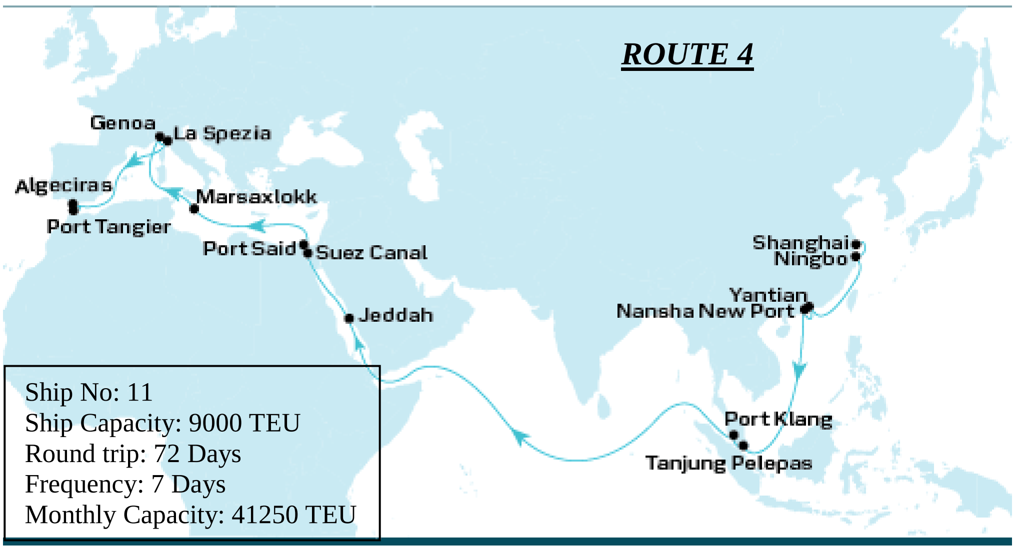



**Figure 21 – Shanghai (China) / Port Tangier Container Line Source: Maersk Line**

Last route from Far East to Mediterranean Sea starts from Shanghai (China) and its turning point is Port Tangier (Morocco). At today circumstances, 9000-TEU 11 ships should be used, these ships creates 41250-TEU monthly capacity from Far East to the Mediterranean Sea for 72-day round trip.

When we looked general overview routes from Far East to the Mediterranean Sea, it can be seen that from below table, two biggest container companies offer 150.750 TEU container capacities from Far East ports to port in the Mediterranean Sea via four routes.

| | Ship no | Frequency (Day) | Round Trip (Day) | Average Ship capacity (TEU) | Monthly Shipment from Far East side (TEU) |
|---|---|---|---|---|---|
| ROUTE 1 | 13 | 7 | 87 | 7250 | 33000 |
| ROUTE 2 | 11 | 7 | 76 | 11250 | 48250 |
| ROUTE 3 | 9 | 7 | 62 | 6500 | 28250 |
| ROUTE 4 | 11 | 7 | 72 | 9000 | 41250 |
| TOTAL | 44 | 7 | | 34000 | 150750 |

**Table 10 – General overview to routes from Far East to the Mediterranean Sea**

## 5.2. A Different Approach to Far East / the Mediterranean Sea Container Traffic

As first part of study, this case offers a different approach for the Mediterranean Sea area that is a hub port system to ensure both of optimum economic benefit and maximum energy efficiency, beside meet demand and supply for the Mediterranean Sea container trade. When it is doing this, as second part of study, two different size container vessels will be used, one of them is 8500-TEU vessel and another one is today's known biggest and most efficient container ship that is 18000-TEU Triple-E class container vessel, and will be compared which one offer more efficient voyages and fleet usage.

***<u>First Part;</u>***

The choice of hub port position was made among located ports in aforementioned countries by calculating ports distances to each port in the Mediterranean Sea. These ports had been already determined as one port in one country. For this choosing, distance calculator tool was used and total distance of every port was calculated. In consequence of this calculation, the shortest three total-distance ports was determined among 24 ports in 23 countries which are

Piraeus/Greece, Candarli/Turkey, and Marsaxlokk/Malta respectively and the following table gives total distances of these three ports. All distances can be seen in Appendix 3.

| PORTS | TOTAL (Nautical Miles) |
|---|---|
| Piraeus/Greece | 16576 |
| Candarli/Turkey | 17368 |
| Marsaxlokk/Malta | 18306 |

**Table 11 – Total distances of the most possible three hub ports Source: Sea-distances.com**

According to these results, possible routes are drawn separately for each potential hub ports which are Piraeus/Greece, Candarli/Turkey, and Marsaxlokk/Malta, on the Mediterranean Sea map. The possible routes can be seen in Appendix 4. These ports have the most suitable locations when compared to other ports in the Mediterranean Sea by analysing their distances to other determined ports in this study. However, this calculation is not sufficient to determine the most appropriate port that will be hub port, so distances were calculated from these three potential hub ports to Port Said, where is the starting point of the sailing in the Mediterranean Sea, while ships are coming from Far East and to aforementioned existing routes. The below table illustrate distances to Port Said and substantial four routes.

| PORTS | Port Said | Route 1 | Route 2 | Route 3 | Route 4 | Total |
|---|---|---|---|---|---|---|
| Piraeus/Greece | 593 | 820 | 1616 | 953 | 2061 | 6043 |
| Candarli/Turkey | 578 | 721 | 1756 | 1094 | 2221 | 6370 |
| Marsaxlokk/Malta | 934 | 1298 | 1099 | 851 | 1534 | 5716 |

**Table 12 – Distances (Nautical Miles) from hub ports to Port Said and existential routes with total value Source: Sea-distances.com**

As seen from Table 12, the total figure gives that the ranking of the most appropriate ports shaped like Marsaxlokk, Piraeus and Candarli, in spite of the ranking of the distance to Port Said shaped like Candarli, Piraeus, and Marsaxlokk. Also, the hub port system provides 1748-NM, 1421-NM and 1094-NM advantages for Marsaxlokk, Piraeus and Candarli respectively. The table 13 demonstrates distances from Port Said to final destinations in existing routes.

| | Route 1 | Route 2 | Route 3 | Route 4 | Total |
|---|---|---|---|---|---|
| Port Said | 1254 | 2033 | 1709 | 2468 | 7464 |

**Table 13 – Distances (Nautical Miles) from Port Said to Final Destinations in Existing Routes**
**Source: Sea-distances.com**

In light of this information, to choose the correct hub port needs in depth analysis of data on hand. For this depth analysis of data, AHP model was used to make decision for the most suitable hub port. The AHP process requires the decision maker to provide judgments about the relative importance of each criterion for each decision alternative. In this study, our alternatives, which had been determined as location of ports, are Piraeus, Candarli and Marsaxlokk. However, we need to pairwise comparisons to compare distance advantage of ports. Therefore, pairwise comparison matrices were constituted by availing oneself of Mangan's lecture hand-outs about AHP modelling (Mangan, 2013). The pairwise comparison scale is given at in table 14.

| Verbal Judgement of Preference | Numerical Rating |
|---|---|
| Extremely Preferred | 9 |
| Very strongly to extremely | 8 |
| Very strongly preferred | 7 |
| Strongly to very strongly | 6 |
| Strongly preferred | 5 |
| Moderately to strongly | 4 |
| Moderately preferred | 3 |
| Equally to moderately | 2 |
| Equally preferred | 1 |

**Table 14 – Pairwise Comparison Scale**

Matrices were constructed as seen in Table 15 by using pairwise comparison scale. Numbers in the scale were assigned to ports as their distance advantages. The pairwise comparison matrices can be seen in Table 15.

| | Distances to | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All Ports | | | Existing Routes | | | Port Said | | |
| | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk |
| Piraeus | 1 | 3 | 8 | 1 | 1/4 | 1/4 | 1 | 1 | 7 |
| Candarli | 1/3 | 1 | 5 | 4 | 1 | 1/8 | 1 | 1 | 8 |
| Marsaxlokk | 1/8 | 1/5 | 1 | 4 | 8 | 1 | 1/7 | 1/8 | 1 |

**Table 15 – Pairwise Comparison Matrices for Distances to All Ports, Existing Routes, and Port Said**

According to results from calculation of the pairwise comparison matrices of criterions, we see that Piraeus Port is the most preferable in terms of distances to all ports (0,657), Marsaxlokk Port is the most preferable in terms of distances to existing routes (0,679) and Candarli Port is the most preferable in terms of distances to Port Said (0,479). The results of this synthesis can be seen in Table 16. No port is the most preferable with respect to all criteria. Therefore, the relative importance of criteria must be assessed for final decision.

| All Ports | Existing Routes | Port Said |
|---|---|---|
| $\begin{bmatrix} 0,657 \\ 0,274 \\ 0,069 \end{bmatrix}$ | $\begin{bmatrix} 0,107 \\ 0,214 \\ 0,679 \end{bmatrix}$ | $\begin{bmatrix} 0,459 \\ 0,479 \\ 0,062 \end{bmatrix}$ |

**Table 16 – Priority Vectors for All Ports, Existing Routes, and Port Said**

In addition to the pairwise comparisons for the decision alternatives, the same pairwise comparison procedures must be used to set priorities for all three criteria in terms of the importance of each. After this procedure, the results obtained as Table 18 by calculating pairwise comparison matrix in Table 17.

| | Criterion | | |
|---|---|---|---|
| | All Ports | Routes | Port Said |
| All ports | 1 | 8 | 2 |
| Existing Routes | 1/8 | 1 | 1/6 |
| Port Said | 1/2 | 6 | 1 |

**Table 17 – Pairwise Comparison Matrix for the Three Criteria in the Port-Selection Problem**

| Priorities for the Three Criteria | |
|---|---|
| All Ports | 0,593 |
| Existing Routes | 0,066 |
| Port Said | 0,341 |

**Table 18 – The Results of Pairwise Judgment to Determine the Most Suitable Port**

As a last part of the port-selection problem, we need to develop an overall priority ranking by using AHP. We will use priority vectors in Table 16 as well as priority values in Table 18 to take final decision for the most suitable hub port.

The procedure used to compute the overall priorities for each decision alternative can best be understood if we think of the priority for each criterion as a weight that reflects its importance. The overall priority for each decision alternative is obtained by summing the ports of the criterion priority times the priority of its decision alternative. The criterion priorities were found to be 0,593 for distance to all ports, 0,066 for distance to existing routes and 0,341 for distance to Port Said. The computation of the overall priority for Piraeus Port is as follows:

Overall Piraeus Port priority = 0,593 (0,657) + 0,066 (0,107) + 0,341 (0,459)
= 0,554

Repeating this calculation for Candarli Port and Marsaxlokk Port provides their overall priorities as follows:

Overall Candarli Port priority = 0,593 (0,274) + 0,066 (0,214) + 0,341 (0,479)
= 0,340

Overall Marsaxlokk Port priority = 0,593 (0,069) + 0,066 (0,679) + 0,341 (0,062)
= 0,106

After the computation, AHP ranking of the decision alternatives appears as follows:

| Alternatives | Priority |
|---|---|
| Piraeus Port | 0,554 |
| Candarli Port | 0,340 |
| Marsaxlokk Port | 0,106 |
| Total | 1,000 |

**Table 19 – AHP Ranking of the Decision Alternatives**

These results help to make decision regarding the most efficient port in terms of distances. According to final results, Piraeus Port should be select as a hub port in the Mediterranean Sea. It is important to create more efficient ports, ships and marine sector and environment. All computations can be seen in Appendix 5. Piraeus Port ensures 1421-NM distance advantage when compared to existing routes distances.

***Second Part;***

In the first part of case study, selection of hub port, which was located in the Middle Mediterranean (Greece), had been made. In this part, two different sizes of container vessel will be analysed and decided for more efficient one to use in Far East – the Mediterranean Sea route.

Today, when looked to lines from Far East to the Mediterranean Sea, used container vessels size changes between 6500 TEU and 13000 TEU as depends on container trade in this route. These container vessels size can be categorised as Post Panamax and New Panamax. Detailed categories of container ship size can be seen in Appendix 6. In the second part of this case study, we will analyse and compare efficiency values when Far East – the Mediterranean Sea container trade is made by Ultra Large Container Vessels (ULCV) instead of today's Post Panamax and New Panamax container vessels in only one main route.

According to analysis of each size of container ships, there are differences up to 43% between fuel consumption of ULCV and 8500-TEU Post Panamax container vessel. The following table shows the fuel consumption values from Tianjin Port (China) to Piraeus Port (Greece).

| | | | CASE A<br>Tianjin to Piraeus (direct)<br>8371 NM | | CASE B<br>Tianjin to Piraeus (Stop by)<br>9500 NM | |
|---|---|---|---|---|---|---|
| | | | Max Speed - 25 knots<br>14 days | | Max Speed - 25 knots<br>16 days | |
| Capacity (TEU) | Daily Consumption (ton/day) | Hourly Consumption (ton/hour) | Total Consumption (ton/voyage) | Per Container (kg/cntr) | Total Consumption (ton/voyage) | Per Container (kg/cntr) |
| 8749 | 211,5 | 8,81 | 2960,1 | 338 | 3383,7 | 387 |
| 18330 | 258,1 | 10,75 | 3613 | 197 | 4129 | 225 |

**Table 20 – Fuel Consumption during Sailing Period from China to the Mediterranean Sea**

The Table 20 shows the fuel consumption during sailing period from Tianjin Port of China to Piraeus Port in Greece at 25-knot speed without including fuel consumption and waiting time in port, drift, anchorage and waiting for Suez Canal passage. The fuel consumption of different size container ships can be seen in Appendix 7.

When we looked the last statistics of container trade from Far-East to Mediterranean Sea, overall container shipment is at level 360,000 TEU per month and created effective westbound container vessel capacity is about 450,000 TEU/month (Drewry, 2013). Therefore, the fleet, from Far-East to the Mediterranean Sea by covering all shipments at this route, should be determined as carrying 450.000 TEU per month at maximum speed (25 knots) and at economical speed (19 knots). While a container ship is sailing at 21 knots, its fuel consumption drops by 33%. However, in this study, it will be got for 19 knots; in spite of reduction of fuel consumption is more than 33% at 19 knots. From the data in Figure 22, it is apparent that the effective slow steaming speed for container vessels economic sails between 18 knots and 20 knots.

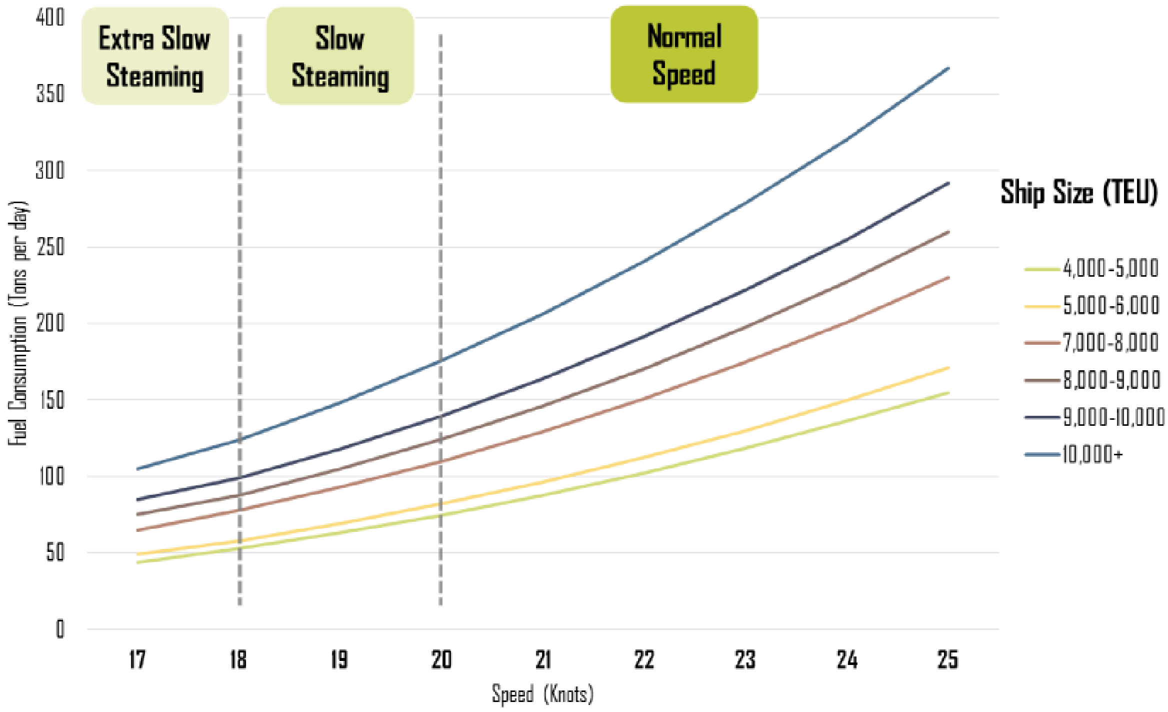



**Figure 22 – The Correlation of Speed – Fuel Consumption Source: Hofstra University, USA**

In order to determine the fleet size, the equation -on page 58 of this study- can be useful and it gives the following results.

| | At Maximum Speed | At Economical Speed |
|---|---|---|
| 18.000 TEU | 45 | 54 |
| 8.500 TEU | 89 | 106 |

**Table 21 – Fleet Size that Meet Monthly Container Capacity from Far-East to the Mediterranean Sea**

The results, which give fleet size to meet container supply/demand in Far-East/the Mediterranean Sea, are obtained by including port times and Suez Canal passage times for CASE B in the Table 20. According to the results, at least 45 ULCV could be used to meet container flow instead of at least 89 Post Panamax Container Vessels at maximum speed (25 knots) on this route. Another option, which is more realistic because of its energy efficient and economical benefits, at least 54 ULCV could be used instead of at least 106 Post Panamax Container Vessels. At these circumstances, the fuel consumption data is obtained for two types of vessels as the follows:

| | 18000 TEU - ULCV | | 8500 TEU - Post Panamax | |
|---|---|---|---|---|
| | At Economical Speed (19 Knots) | At Maximum Speed (25 Knots) | At Economical Speed (19 Knots) | At Maximum Speed (25 Knots) |
| Number of ship | 54 | 45 | 106 | 89 |
| Days per Round Trip | 64 | 54 | 60 | 50 |
| Frequency | 1,19 | 1,2 | 0,57 | 0,56 |
| Fuel Consumption (ton/day) | 162,60 | 258,10 | 141,71 | 211,50 |
| Fuel Consumption (ton/voyage) | 3414,66 | 4129,00 | 2975,81 | 3383,70 |
| Fuel Consumption (ton/container) | 0,186 | 0,225 | 0,351 | 0,387 |
| Fuel Consumption (ton/fleet) | 561955,968 | 627183 | 901243,8 | 941175 |

**Table 22 – Fuel Consumption Values for 9500-NM Far-East/the Mediterranean Sea Route**

When the fuel consumption values are analysed, it can be seen that the hub port system makes a world of difference when ULCVs are combined to the hub port system. When ULCVs are used instead of Post Panamax Container Vessels, the most striking result to emerge from the data that total fuel saving can reach up to 340.000 ton/fleet for one round trip. Its percentage equivalent reaches up to 38%. In this situation, benefits are obtained from the following titles;

*Lower speed:* Vessels are designed for lower speed, because a small change in knots cuts fuel consumption and lowers $CO_2$ emissions.

*Economy of scale:* By increasing ship capacity, more efficient voyages could be designed without requiring more engine power.

The results, the importance of the results and their effects to energy efficiency will be discussed in the next chapter; Results and Discussion.

# 6. RESULTS & DISCUSSION

The last chapter illustrates the results of port and fleet organization on energy efficiency by studying on a specific case. The findings from the case study suggest that the operational measures can generate more efficient and greener ships, ports and marine environment. It can be seen from the results of the case study that a positive correlation was found between suggested port and fleet settlement and energy saving. Therefore, these measures might be named as real operational solutions for energy efficiency.

The aims of operational measures is to increase vessel sailing time and ton-miles ratio by adapting some operational methods such as hub port system, slow steaming, larger vessel usage etc., because the meaning of the increasing of the loaded sailing time of vessel and ton-miles ratio is that more energy saving. The following pie chart demonstrates operation modes in percentage. Although, the percentage of sea passage laden is the biggest in other operation modes, the ratio of other modes is bigger than the sea passage laden in total.

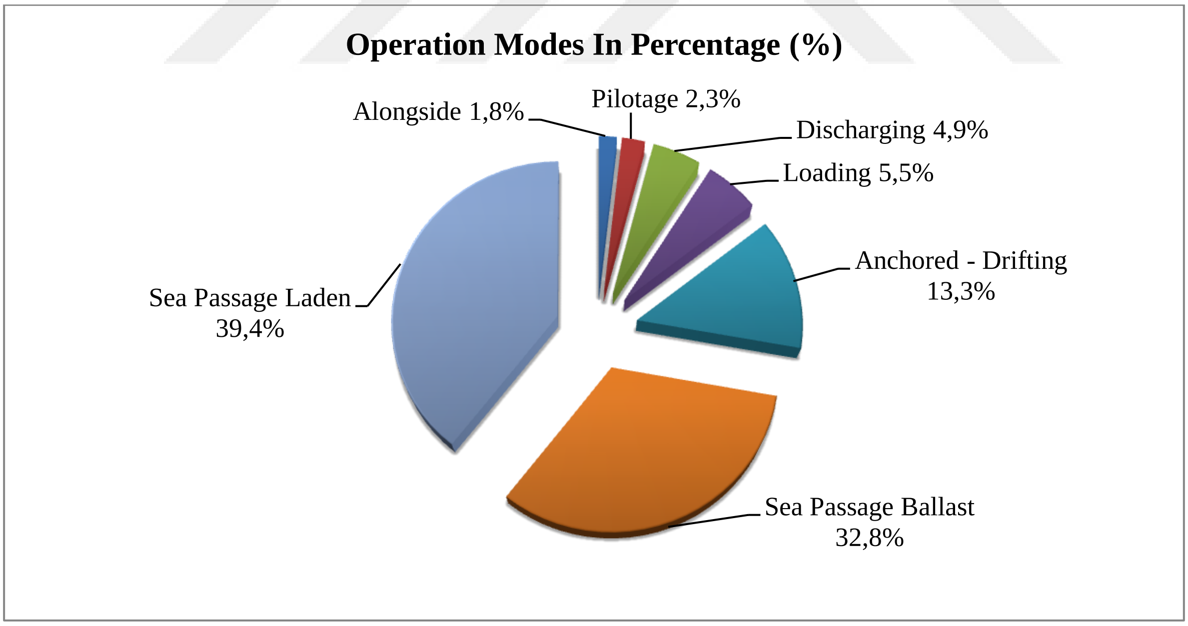



**Figure 23 - Operation Modes as a percentage of total voyage duration time (IMO, 2009d)**

In other saying, the objective of the operational solutions is that increase of sea passage laden rate, which affects the ton-miles ratio automatically in positive direction, in other operation modes and decline of other modes rates which are sea passage ballast, anchored – drifting, loading, discharging, pilotage and alongside, against loaded vessel sailing time.

The case study offers to spend less port time by declining number of ports thanks to hub port system. It directly makes a positive effect to ton-mile values. Furthermore, the main point of usage larger ships in fleet is that increasing ton-miles values of ships of used fleet in the case study. When looked to case from this perspective, these positive efficiency adjuvant results can be attributed to operational solutions. Yet, generation of efficient ships and marine environment starts from structuring stage to scrapping stage by adapting new efficient improved technologies and alternative fuels as well. Hence, it cannot be only attributed to operational measures; these positive results express the great combination of technical and operational measures and systems since the first day of maritime sector.

The present case study was designed to determine the effects of hub port system and suitable fleet size with slow steaming application to marine sector by creating fuel saving. It is apparent from the case study that an appropriate port system and fleet size could ensure an effective energy saving by reducing energy consumption. However, there are several factors which could affect the impacts of the operational solutions, such as strategic, methodological, physical, politic and economic. The factors impacts are related to the implementation of the right strategy by the right methodology at the right physical, politic and economic settings.

This study produced results which corroborate the findings of a great deal of the previous work in this field. These results were environmentally very encouraging, but the results were handled by energy saving side. However, these findings will doubtless be much scrutinized, despite there are some immediately dependable conclusions for environment and green shipping methods. When looking from environment and energy efficiency side, the results can create a glorious advantage for implementation areas. However, these results should also be assessed by approaching physical, politic and economic sides in order to determine that the results are feasible or not. If this study is not developed, it can remain weak and several questions remain unanswered at present. Thus, further research should be done to investigate the port system and fleet structure and management in physical, politic and economic respects.

Aforementioned in this chapter, operational solutions can create tableaux if they are used in the right strategy by right methods. In the case study of this paper, a hub port system is constituted by analysing its distance advantages. It is aimed from this case study that improving energy efficiency by increasing sailing time thanks to hub port system. Concordantly, this case study can be practicable thanks to its great advantages. Yet, the following factors in the list were not calculated and/or analysed.

- capacity of port,
- infrastructures of port,
- hinterland of port,
- draught of port,
- handling facilities of port,
- number of cranes,
- number of piers,
- number of container and other cargo terminals,
- other equipment,
- company and government policies and strategies,
- other elusive stuff

As second part of the case study, two different fleet sizes were analysed and their fuel consumptions were calculated. The results from the computation were very encouraging to implement new fleet size to Far-East/the Mediterranean Sea. However, the situation was same as hub port system, and the findings were obtained by analysing exclusively energy efficiency and fuel consumption.  Nevertheless, in order to build an extraordinary-advantage fleet, factors in each step from construction stage to demolition stage should be analysed and its advantages and disadvantages should be explored. Examples of factors are given in the following list;

- economic circumstances of companies which will make investment,
- building capability of shipyards,
- delivery times of ships,
- market shares of company,
- loaded rates of ships,
- light leg/heavy leg situation of route,
- the future of current ships,

- future market forecasts,
- other technical and operational investments and costs to operate ships more effective,
- scrapping

The above factors can be subcategorised under physical, politic and economic factors. All of these factors might affect energy efficient feasibility, which is focus area of this study, and also economic, politic, physical feasibility. There is just one way to understand the feasibility of port that is to make in depth analysis of each factor. In the present case, more research on these topics need to be undertaken before the association between the case study and its feasibility is more clearly understood.

# 7. CONCLUSION

This dissertation has explained the central importance of operational approaches in energy efficiency. While it was explaining the importance of operational measures, it looked at literature review of energy efficiency, regulations and it implemented operational measures in a case study by using determined known methods.

The notion of energy efficiency cannot be assessed from acute angled perspective; it needs to see whole picture to obtain energy efficiency in real terms. In this context, approaching to energy efficiency from one side like technical, operational blocks to assess in real values and to reach major potential of fuel saving.

At MEPC 62 in July 2011, the mandatory implementation of the EEDI and SEEMP was agreed. As it has been mentioned before, while EEDI is presenting technical design part of energy efficiency for new ships, SEEMP presents operational part. However, their effective implementation is directly related to human resources and responsibilities. Appointed people on board and ashore has a great role to put in practice these regulations. A fool proof SEEMP can decline pressure on people and EEOI values to improve energy efficiency. This change energy efficiency related approach from human-driven to system-driven.

Consequentially, what I am trying to say in this dissertation that each measure is a step to create more efficient, energy saving eco-designed ships and marine environment, and all make contribution in a certain extent itself. However, the main focus point is here that combined application of these measures will ensure comprising of required picture. Therefore, all measures and also policy makers and industry players in marine sector have a great role to create more efficient, administratively well-organised, eco-friendly, innovative and sustainable port system, and ship operations.

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# 9. APPENDICES

## APPENDIX 1 – List of Parameters that Affect the EEDI

The following are provided as a list of typical parameters which may have an effect on the ship's EEDI.

Note: This is not an exhaustive list.

1. Ship type and design for ice
2. Type of fuel
3. Size and specific fuel consumption of main engines (or main propulsion motors)
4. Specific fuel consumption of auxiliary (power generation) engines
5. Hull form
6. Hull appendices
7. Propeller
8. Electric power requirement for non-propulsion systems
9. Capacity at summer load line
10. Draft and trim at summer load line
11. Energy saving devices as specified in EEDI Technical File

# APPENDIX 2 – A Sample Form of a SEEMP

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APPENDIX

A SAMPLE FORM OF A SHIP EFFICIENCY ENERGY MANAGEMENT PLAN

| | | | |
|---|---|---|---|
| Name of Vessel: | | GT: | |
| Vessel Type: | | Capacity: | |

| | | | |
|---|---|---|---|
| Date of Development: | | Developed by: | |
| Implementation Period: | From:<br>Until: | Implemented by: | |
| Planned Date of Next Evaluation: | | | |

1 MEASURES

| Energy Efficiency Measures | Implementation (including the starting date) | Responsible Personnel |
|---|---|---|
| Weather Routeing | <Example><br>Contracted with [Service providers] to use their weather routeing system and start using on-trial basis as of 1 July 2012. | <Example><br>The master is responsible for selecting the optimum route based on the information provided by [Service providers]. |
| Speed Optimization | While the design speed (85% MCR) is 19.0 kt, the maximum speed is set at 17.0 kt as of 1 July 2012. | The master is responsible for keeping the ship's speed. The log-book entry should be checked every day. |
| | | |
| | | |
| | | |

2 MONITORING

Description of monitoring tools

3 GOAL

Measurable goals

4 EVALUATION

Procedures of evaluation

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# APPENDIX 3 – Distances of Ports to Each Port in the Mediterranean Sea

| | Georgia/Poti | Russia/Novorossiysk | Ukraine/Sevastopol | Romania/ Constanta | Bulgaria/Varna | Turkey/Ambarlı | Turkey/Candarlı | Greece/Piraeus | Albania/Vlore | Croatia / Rijeka | Slovenia/ Koper | Italy/La Spezia | France/Marseille | Spain/Valencia | Morocco/Port of Nador | Algeria/Port of Algiers | Tunisia/Sfax | Malta/Marsaxlokk | Libya/Tripoli | Egypt/Alexandria | Israel/ Haifa | Lebanon/Beirut | Syria/Latakia | Cyprus/Limassol | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Georgia/Poti | 0 | 227 | 403 | 579 | 613 | 588 | 856 | 955 | 1356 | 1715 | 1751 | 1852 | 1981 | 2153 | 2288 | 1987 | 1652 | 1433 | 1551 | 1325 | 1419 | 1413 | 1393 | 1295 | 30785 |
| Russia/Novorossiysk | 227 | 0 | 219 | 402 | 440 | 471 | 709 | 808 | 1209 | 1568 | 1604 | 1705 | 1834 | 2006 | 2141 | 1840 | 1505 | 1286 | 1404 | 1178 | 1272 | 1266 | 1246 | 1148 | 27488 |
| Ukraine/Sevastopol | 403 | 219 | 0 | 212 | 254 | 314 | 552 | 651 | 1052 | 1411 | 1447 | 1548 | 1677 | 1849 | 1984 | 1683 | 1348 | 1129 | 1247 | 1021 | 1115 | 1109 | 1089 | 991 | 24305 |
| Romania/ Constanta | 579 | 402 | 212 | 0 | 76 | 211 | 449 | 548 | 949 | 1308 | 1344 | 1445 | 1574 | 1746 | 1881 | 1580 | 1245 | 1026 | 1144 | 918 | 1012 | 1006 | 986 | 888 | 22529 |
| Bulgaria/Varna | 613 | 440 | 254 | 76 | 0 | 164 | 402 | 501 | 902 | 1261 | 1297 | 1398 | 1527 | 1699 | 1834 | 1533 | 1198 | 979 | 1097 | 871 | 965 | 959 | 939 | 841 | 21750 |
| Turkey/Ambarlı | 588 | 471 | 314 | 211 | 164 | 0 | 238 | 337 | 738 | 1097 | 1133 | 1234 | 1363 | 1535 | 1670 | 1369 | 1034 | 815 | 933 | 707 | 801 | 795 | 775 | 677 | 18999 |
| Turkey/Candarlı | 856 | 709 | 552 | 449 | 402 | 238 | 0 | 184 | 580 | 939 | 976 | 1076 | 1205 | 1377 | 1512 | 1211 | 876 | 657 | 775 | 514 | 609 | 603 | 583 | 485 | 17368 |
| Greece/Piraeus | 955 | 808 | 651 | 548 | 501 | 337 | 184 | 0 | 440 | 800 | 835 | 936 | 1065 | 1237 | 1372 | 1071 | 736 | 517 | 635 | 512 | 642 | 643 | 626 | 525 | 16576 |
| Albania/Vlore | 1356 | 1209 | 1052 | 949 | 902 | 738 | 580 | 440 | 0 | 395 | 431 | 707 | 836 | 1020 | 1173 | 872 | 568 | 369 | 547 | 790 | 962 | 966 | 961 | 849 | 18672 |
| Croatia / Rijeka | 1715 | 1568 | 1411 | 1308 | 1261 | 1097 | 939 | 800 | 395 | 0 | 106 | 1035 | 1164 | 1348 | 1501 | 1200 | 898 | 696 | 876 | 1151 | 1323 | 1327 | 1322 | 1210 | 25651 |
| Slovenia/ Koper | 1751 | 1604 | 1447 | 1344 | 1297 | 1133 | 976 | 835 | 431 | 106 | 0 | 1071 | 1200 | 1384 | 1537 | 1236 | 934 | 732 | 912 | 1187 | 1359 | 1363 | 1358 | 1246 | 26443 |
| Italy/La Spezia | 1852 | 1705 | 1548 | 1445 | 1398 | 1234 | 1076 | 936 | 707 | 1035 | 1071 | 0 | 228 | 537 | 803 | 533 | 626 | 559 | 688 | 1276 | 1460 | 1464 | 1457 | 1347 | 24985 |
| France/Marseille | 1981 | 1834 | 1677 | 1574 | 1527 | 1363 | 1205 | 1065 | 836 | 1164 | 1200 | 228 | 0 | 345 | 618 | 410 | 674 | 645 | 742 | 1405 | 1589 | 1593 | 1586 | 1476 | 26737 |
| Spain/Valencia | 2153 | 2006 | 1849 | 1746 | 1699 | 1535 | 1377 | 1237 | 1020 | 1348 | 1384 | 537 | 345 | 0 | 316 | 226 | 762 | 750 | 830 | 1554 | 1755 | 1760 | 1758 | 1643 | 29590 |
| Morocco/ Nador | 2288 | 2141 | 1984 | 1881 | 1834 | 1670 | 1512 | 1372 | 1173 | 1501 | 1537 | 803 | 618 | 316 | 0 | 304 | 896 | 884 | 964 | 1689 | 1890 | 1895 | 1893 | 1778 | 32823 |
| Algeria/ Algiers | 1987 | 1840 | 1683 | 1580 | 1533 | 1369 | 1211 | 1071 | 872 | 1200 | 1236 | 533 | 410 | 226 | 304 | 0 | 595 | 583 | 663 | 1388 | 1589 | 1594 | 1592 | 1477 | 26536 |
| Tunisia/Sfax | 1652 | 1505 | 1348 | 1245 | 1198 | 1034 | 876 | 736 | 568 | 898 | 934 | 626 | 674 | 762 | 896 | 595 | 0 | 217 | 161 | 988 | 1220 | 1235 | 1240 | 1116 | 21724 |
| Malta/Marsaxlokk | 1433 | 1286 | 1129 | 1026 | 979 | 815 | 657 | 517 | 369 | 696 | 732 | 559 | 645 | 750 | 884 | 583 | 217 | 0 | 191 | 819 | 1027 | 1037 | 1036 | 919 | 18306 |
| Libya/Tripoli | 1551 | 1404 | 1247 | 1144 | 1097 | 933 | 775 | 635 | 547 | 876 | 912 | 688 | 742 | 830 | 964 | 663 | 161 | 191 | 0 | 860 | 1100 | 1118 | 1149 | 1005 | 20592 |
| Egypt/Alexandria | 1325 | 1178 | 1021 | 918 | 871 | 707 | 514 | 512 | 790 | 1151 | 1187 | 1276 | 1405 | 1554 | 1689 | 1388 | 988 | 819 | 860 | 0 | 292 | 340 | 400 | 271 | 21456 |
| Israel/ Haifa | 1419 | 1272 | 1115 | 1012 | 965 | 801 | 609 | 642 | 962 | 1323 | 1359 | 1460 | 1589 | 1755 | 1890 | 1589 | 1220 | 1027 | 1100 | 292 | 0 | 72 | 169 | 144 | 23786 |
| Lebanon/Beirut | 1413 | 1266 | 1109 | 1006 | 959 | 795 | 603 | 643 | 966 | 1327 | 1363 | 1464 | 1593 | 1760 | 1895 | 1594 | 1235 | 1037 | 1118 | 340 | 72 | 0 | 100 | 132 | 23790 |
| Syria/Latakia | 1393 | 1246 | 1089 | 986 | 939 | 775 | 583 | 626 | 961 | 1322 | 1358 | 1457 | 1586 | 1758 | 1893 | 1592 | 1240 | 1036 | 1149 | 400 | 169 | 100 | 0 | 145 | 23803 |
| Cyprus/Limassol | 1295 | 1148 | 991 | 888 | 841 | 677 | 485 | 525 | 849 | 1210 | 1246 | 1347 | 1476 | 1643 | 1778 | 1477 | 1116 | 919 | 1005 | 271 | 144 | 132 | 145 | 0 | 21608 |

## APPENDIX 4 – Demonstration of Routes on Map Starts from Three Potential Hub Ports in the Mediterranean Sea


**Figure 24 – Routes from Piraeus / Greece**

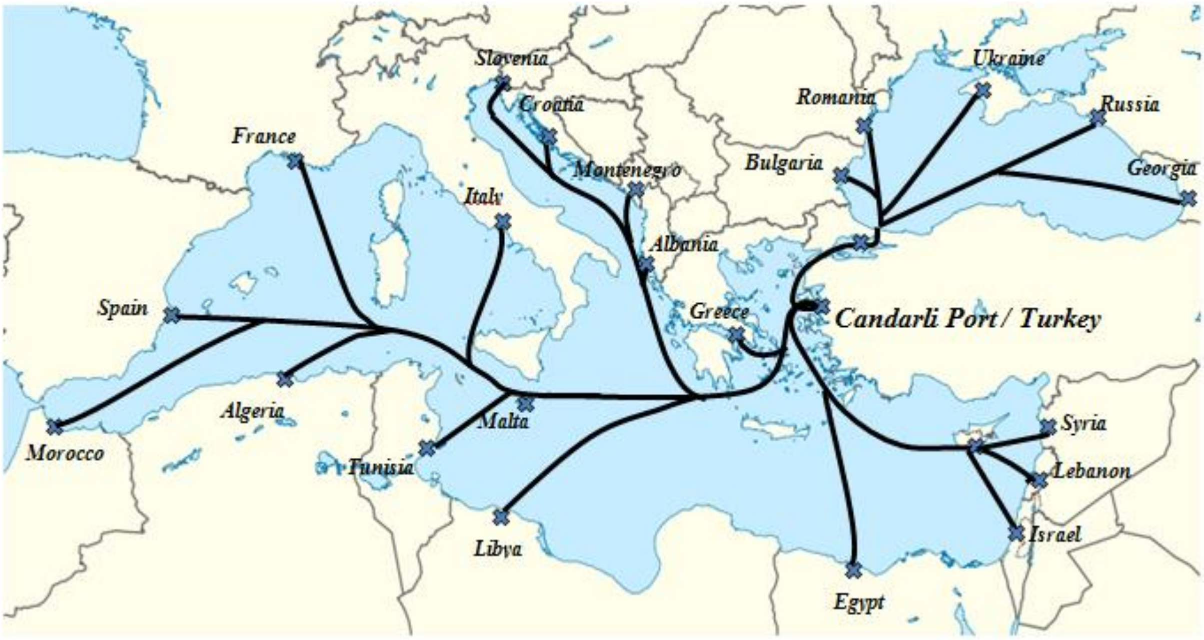


**Figure 25 – Routes from Candarli Port / Turkey**


**Figure 26 – Routes from Marsaxlokk Port / Malta**

# APPENDIX 5 – Selecting of the Most Suitable Hub Port by Using AHP

| Verbal Judgement of Preference | Numerical Rating |
|---|---|
| Extremely Preferred | 9 |
| Very strongly to extremely | 8 |
| Very strongly preferred | 7 |
| Strongly to very strongly | 6 |
| Strongly preferred | 5 |
| Moderately to strongly | 4 |
| Moderately preferred | 3 |
| Equally to moderately | 2 |
| Equally preferred | 1 |

**(Pairwise Comparison Scale for AHP Preferences)**

| | Distances to | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All Ports | | | Existing Routes | | | Port Said | | |
| | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk |
| Piraeus | 1 | 3 | 8 | 1 | 1/4 | 1/4 | 1 | 1 | 7 |
| Candarli | 1/3 | 1 | 5 | 4 | 1 | 1/8 | 1 | 1 | 8 |
| Marsaxlokk | 1/8 | 1/5 | 1 | 4 | 8 | 1 | 1/7 | 1/8 | 1 |

**(Pairwise Comparison Matrices)**

| | Distances to | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All Ports | | | Existing Routes | | | Port Said | | |
| | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk |
| Piraeus | 1 | 3 | 8 | 1 | 1/4 | 1/4 | 1 | 1 | 7 |
| Candarli | 1/3 | 1 | 5 | 4 | 1 | 1/8 | 1 | 1 | 8 |
| Marsaxlokk | 1/8 | 1/5 | 1 | 4 | 8 | 1 | 1/7 | 1/8 | 1 |
| Columns Total | 35/24 | 21/5 | 14 | 9 | 37/4 | 11/8 | 15/7 | 17/8 | 16 |

**(Step 1: Sum of values in each columns)**

| | Distances to | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | All Ports | | | Existing Routes | | | Port Said | | |
| | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk | Piraeus | Candarli | Marsaxlokk |
| Piraeus | 24/35 | 15/21 | 8/14 | 1/9 | 1/37 | 2/11 | 7/15 | 8/17 | 7/16 |
| Candarli | 24/105 | 5/21 | 5/14 | 4/9 | 4/37 | 1/11 | 7/15 | 8/17 | 1/2 |
| Marsaxlokk | 3/35 | 1/21 | 1/14 | 4/9 | 32/37 | 8/11 | 1/15 | 1/17 | 1/16 |

**(Step 2: Divide each element of the matrix by its column total)**

| | Distances to | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All Ports | | | Row Average | Existing Routes | | | Row Average | Port Said | | | Row Average |
| | Piraeus | Candarli | Marsaxlokk | | Piraeus | Candarli | Marsaxlokk | | Piraeus | Candarli | Marsaxlokk | |
| Piraeus | 0,686 | 0,714 | 0,572 | 0,657 | 0,112 | 0,027 | 0,182 | 0,107 | 0,467 | 0,471 | 0,438 | 0,459 |
| Candarli | 0,228 | 0,238 | 0,357 | 0,274 | 0,444 | 0,108 | 0,091 | 0,214 | 0,467 | 0,471 | 0,500 | 0,479 |
| Marsaxlokk | 0,086 | 0,048 | 0,071 | 0,069 | 0,444 | 0,865 | 0,727 | 0,679 | 0,066 | 0,058 | 0,062 | 0,062 |
| | | | Total | 1,000 | | | Total | 1,000 | | | Total | 1,000 |

**(Step 3: Average the elements in each row)**

| All Ports | Existing Routes | Port Said |
|---|---|---|
| 0,657 | 0,107 | 0,459 |
| 0,274 | 0,214 | 0,479 |
| 0,069 | 0,679 | 0,062 |

**(Priority Vectors for Each Element)**

| | Criterion | | |
|---|---|---|---|
| | All Ports | Routes | Port Said |
| All ports | 1 | 8 | 2 |
| Routes | 1/8 | 1 | 1/6 |
| Port Said | 1/2 | 6 | 1 |

**(Pairwise Comparison Matrix for Three Criteria in the Port-Selection Problem)**

| | Criterion | | |
|---|---|---|---|
| | All Ports | Routes | Port Said |
| All ports | 1 | 8 | 2 |
| Routes | 1/8 | 1 | 1/6 |
| Port Said | 1/2 | 6 | 1 |
| Columns Total | 13/8 | 15 | 19/6 |

**(Step 1)**

| | Criterion | | |
|---|---|---|---|
| | All Ports | Routes | Port Said |
| All ports | 8/13 | 8/15 | 12/19 |
| Routes | 1/13 | 1/15 | 1/19 |
| Port Said | 4/13 | 6/15 | 6/19 |

**(Step 2)**

| | Criterion | | | Row Average |
|---|---|---|---|---|
| | All Ports | Routes | Port Said | |
| All ports | 0,615 | 0,533 | 0,632 | 0,593 |
| Routes | 0,077 | 0,067 | 0,053 | 0,066 |
| Port Said | 0,308 | 0,400 | 0,315 | 0,341 |
| | | | Total | 1,000 |

**(Step 3)**

| Priorities for the Three Criteria | |
|---|---|
| All Ports | 0,593 |
| Routes | 0,066 |
| Port Said | 0,341 |

**(The result of Pairwise Comparison Matrix for the Three Criteria)**

Overall Candarli Port priority = 0,593 (0,274) + 0,066 (0,214) + 0,341 (0,479)
= 0,340

Overall Marsaxlokk Port priority = 0,593 (0,069) + 0,066 (0,679) + 0,341 (0,062)
= 0,106

Overall Piraeus Port priority = 0,593 (0,657) + 0,066 (0,107) + 0,341 (0,459)
= 0,554

| Alternatives | Priority |
|---|---|
| Piraeus Port | 0,554 √ |
| Candarli Port | 0,340 |
| Marsaxlokk Port | 0,106 |
| Total | 1,000 |

**(The Final Decision)**

# APPENDIX 6 – Container Ship Size Categories

| Name | Capacity (TEU) | Length | Beam | Draft |
|---|---|---|---|---|
| Ultra Large Container Vessel (ULCV) | 14,501 and higher | 1,200 ft (366 m) and longer | 160,7 ft (49 m) and wider | 49,9 ft (15,2 m) and deeper |
| New Panamax | 10,001 - 14,500 | 1,200 ft (366 m) | 160,7 ft (49 m) | 49,9 ft (15,2 m) |
| Post Panamax | 5,101 - 10,000 | | | |
| Panamax | 3.001 - 5,100 | 965 ft (294,13 m) | 106 ft (32,21 m) | 39,5 ft (12,04 m) |
| Feedermax | 2,001 - 3,000 | | | |
| Feeder | 1,001 - 2000 | | | |
| Small Feeder | up to 1000 | | | |

**Table 23 – Container Ship Size Categories**

## APPENDIX 7 – Fuel Consumption of Different Size of Container Ships

| | | | Tianjin to Piraeus (direct) - 8371 NM Max Speed - 25 knots - 14 days | | Tianjin to Piraeus (Stop by) - 9500 NM Max Speed - 25 knots -16 days | |
|---|---|---|---|---|---|---|
| Capacity (TEU) | Daily Consumption (ton/day) | Hourly Consumption (ton/hour) | Total Consumption (ton/voyage) | Per Container (kg/container) | Total Consumption (ton/voyage) | Per Container (kg/container) |
| 6572 | 175,1 | 7,3 | 2451,4 | 373 | 2801,6 | 426 |
| 7024 | 178,5 | 7,4 | 2499 | 356 | 2856 | 407 |
| 8468 | 211 | 8,79 | 2953,6 | 349 | 3376 | 399 |
| 8749 | 211,5 | 8,81 | 2960,1 | 338 | 3383,7 | 387 |
| 9043 | 196,7 | 8,2 | 2753,7 | 305 | 3147 | 348 |
| 11356 | 222,2 | 9,26 | 3111 | 274 | 3555 | 313 |
| 13092 | 220,2 | 9,17 | 3082 | 235 | 3522 | 269 |
| 15550 | 279,7 | 11,65 | 3915 | 252 | 4474 | 288 |
| 16022 | 245,3 | 10,22 | 3433 | 214 | 3924 | 245 |
| 18330 | 258,1 | 10,75 | 3613 | 197 | 4129 | 225 |

**Table 24 – Fuel Consumption during Sailing Period from China to the Mediterranean Sea via Suez Canal**