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IMPROVING ENERGY EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY OF A BULK CARRIER

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IRTOLASTILAIVAN ENERGIATEHOKKUUDEN JA YMPÄRISTÖYSTÄVÄLLISYYDEN PARANTAMINEN

Tämä opinnäytetyö tehtiin suomalaiselle energiatehokkuuteen ja ympäristötekniikkaan keskittyneeseen yritykseen Biota Techiin, joka sijaitsee Turussa. Tarkoituksena oli suorittaa kirjallisuustutkimuksella yleiskartoitus irtolastialuksen tuottamista päästöistä sekä mahdollisuuksista vähentää niitä.

Käsiteltävä alus on M/S Belland –niminen 3000 DWT :n kauppalaiva, joka operoi lähinnä Itämeren alueella. Laiva on rakennettu Saksassa Sietaksen telakalla 1986, josta johtuen se sisältää 25 vuotta vanhaa tekniikkaa, jota päivittämällä päästöjä saataisiin vähennetyksi mutta suuret päivitystoimenpiteen eivät kuitenkaan ole taloudellisesti kannattavia eikä näin ollen varteenotettavia.

ASIASANAT:

Energiankulutus, tehokkuus, päästöt, laivaliikenteen ympäristökuormitus

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IMPROVING ENERGY EFFICIENCY AND ENVIRONMENTAL SUSTAINABILITY OF A BULK CARRIER

This thesis was commissioned by Biota Tech, a Finnish engineering and consulting company specialized in environmental technology and energy efficiency, located in Turku. During fall 2010 it was decided to carry out a thesis concerning a bulk carrier M/S Belland Valletta and shipping emissions.

The purpose was to find tools to decrease her energy consumption and find a more environmentally friendly way to operate. As it was difficult to improve the situation of this particular ship the thesis was expanded to general shipping emissions as well.

It was noticed that the bulker contains old equipment due to its age and it may be possible to find major benefits in upgrading some pieces of equipment. However, the upgrading of old equipment was not a financially realistic option.

KEY WORDS: Bulk carrier, emissions, energy efficiency

FIGURES

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List of Abbreviations

BSR	Baltic Sea Region
CDP	Controlled Depletion Polymer
CO_2	Carbon Dioxide
DWAT	Dead Weight All Told
DWCC	Dead Weight Cargo Capacity
ECA	Emission Control Area
EPA	US Environmental Protection Agency
EU	European Union
FRC	Foul Release Coating
GO	Gas Oil
GT	Gross Tonnage
HELCOM	Baltic Marine Environment Protection Commission
HFO	Heavy Fuel Oil
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
L_{OA}	Length Overall
LS	Low Sulfur
LTD	Limited Company
M/S	Motor Ship

MDO	Marine Diesel Oil
NO_x	Nitrogen Oxide
NT	Net Tonnage
OWS	Oily Water Separator
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
PR	Public Relations
PRF	Port Reception Facility
SO_X	Sulfur Oxide
SPC	Self Polishing Copolymer
TBT	Organotin Compound Tributyltin
TEU	Twenty Foot Equivalent Unit

1. INTRODUCTION

1.1 Background

This thesis was commissioned by Biota Tech located in Turku. Biota Tech, Biota BD until the year 2008, is a private Finnish engineering and consulting company specialized in environmental technology and energy efficiency. Biota Tech was founded in 1997 to collaborate with the universities in the Turku region, and today it is part of Meriaura Group. Meriaura Group consist of five other enterprises which operate in marine transport, logistics, environmental technology and in the administrational sector: Meriaura Oy, the shipping company VG-Shipping Oy, shipbuilding industrial transportation services providing Pernotrans Oy, biofuel producing Sybimar Oy and administrational and information services providing Aura Mare Oy. The enterprises of Meriaura Group constitute a multifaceted energy-, and logistics entity.

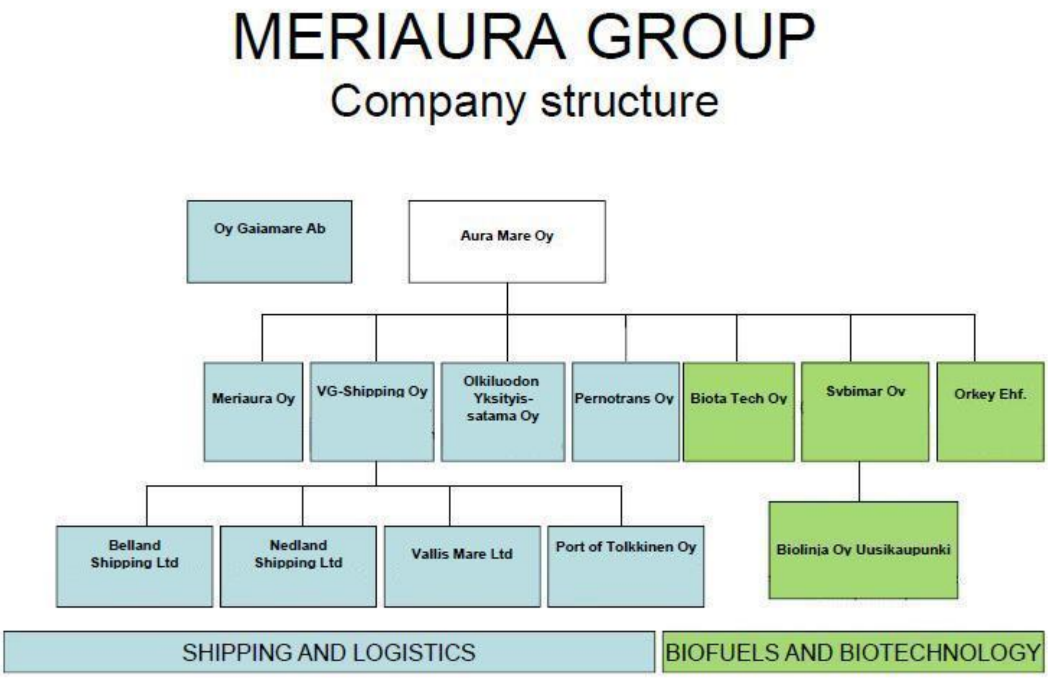

Figure 1. Company structure

Nowadays, Biota Tech is participating in many projects concerning energy efficiency and renewable energy. Besides domestic projects, there are other co-operational projects in Europe and Latin America. Biota Tech Oy know-how fields encompass all stages of the project including assessment, planning and realization.

During fall 2010 was decided to carry out an energy efficiency report concerning a bulk carrier M/S Belland Valletta. The title of the thesis: “Improving the energy efficiency and environmental sustainability of a bulk carrier” describes the values and business mission of Biota Tech Oy.

1.2 Objectives

The purpose was to find tools to decrease its energy consumption and find a more environmentally friendly way to operate it. An additional target was to reconcile the economic needs with the ecological issues but in some cases they did not converge. For that reason the maintenance and repair costs are taken into account. This means that all characteristics of the bulker have to be taken into account but a certain statistical value, for example -20% less lubrication oil consumption, cannot be met. Still, an estimation of costs can be conducted but it will not be very accurate.

1.3 Scope and limitations

The lack of monitoring of the fuel economy, the real time fuel consumption, in M/S Belland, and in other merchant ships, forces to estimate the optimal load rate in every situation. Voyage reports provide exact data on loading and refueling, but they do not contain data on the weather. The fuel consumption is higher in winter due to the more challenging navigation conditions caused by the ice coverage.

1.4 Methods

The main focus was on a literary research and on the voyage reports. Some parts of the voyage report data can be summoned up to one Excel chart to create specific trend lines and calculate average values. However, M/S Belland has been operated under Meriaura for approximately one and a half year so a reliable cost analysis could not have been done.

Approximately one year's voyage reports were analyzed to find whether there exist some trends and similarities. A wide-ranging literary research was also carried out not only to find similar theses and a possible reference ship but also to describe the problematic environmental issues around the global marine traffic. In environmental issues, the focus was on the Baltic Sea Region and thus some results could be hard to generalize to other regions. It was noticed that the bulker contains old equipment due to its age and it may be possible to find major benefits in upgrading some pieces of equipment. In this case, the economic needs would not reconcile with the ecological improvements.

2. M/S BELLAND

M/S Belland is a bulk carrier built in Sietas shipyard in 1986. The particulars are given in Table 1.

Table 1. M/S Belland

Owner	Belland Shipping LTD
TC-owner	Meriaura LTD
Call sign	9HA2261
Imo	8609618
Built	1986 Sietas Hamburg
Classification	LRS+110A1 Lloyd's register class 1A
Flag	Malta
Crew	International
Pandi	Transsecure / Fairwater / Alandia
GT / NT	2673 / 1009
DWAT / DWCC	3004 / 2850
L_{oa} (m)	87,99
Breadth (m)	12,8
Draught (m)	4,68
Main engine	Wärtsilä Vasa 6R32BC, 1839 kW
Bow thruster	180 kW
Speed laden	12,5 kn
Cargo hatch	One hatch, 56,03 x 10,4 m
Cargo hold	One hold, steel tank top, box shaped, grain fitted, timber fitted

2.1 Hold capacity and cargo types

M/S Belland has one cargo hold and one cargo hatch of 56,0 x 10,4 meters. M/S Belland does not have its own crane. Cargo hold is between frames 30 until 120 with distance between frames 650 mm.

Table 2. M/S Belland hold capacity

Cargo type	Volume (m^3)	Volume (Sq Ft)
Grain	4920	174734
Bale	4855	172425
Timber	4400	156266
	In hold (TEU)	On deck (TEU)
Containers	108	90

An optimal load situation would be when the maximum volume is reached with the cargo and minimum, or none, amount of ballast water is needed. However, this scenario is quite unrealistic because ballast water is usually needed in the bottom tanks for maintaining the stability when cargo is full.[1]

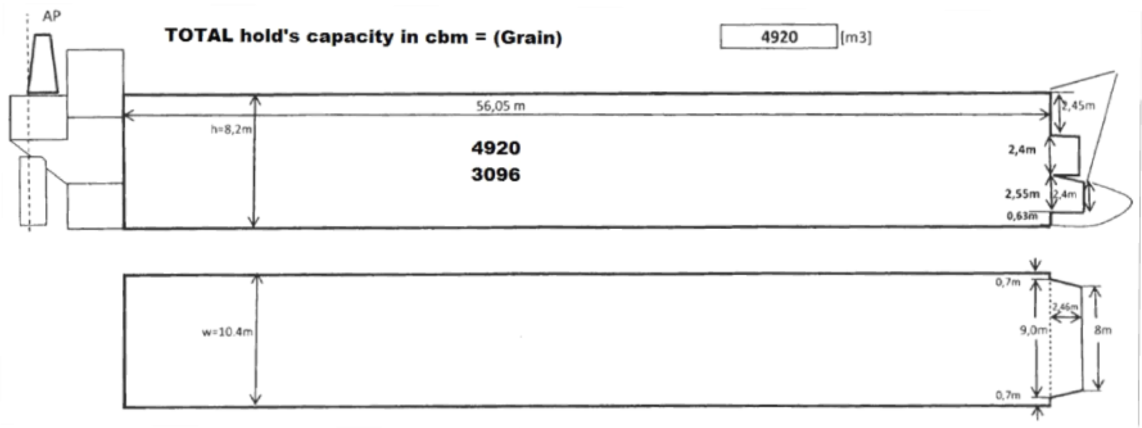

Figure 2. Hold Capacity of M/S Belland

A maximum loading capacity tends to fluctuate due to the nature of cargo. For grain it is around 98% of the total volume of the cargo hold. The size of cargo hold can be seen in Figure 2. It has to be noted that M/S Belland does not have the Document of Compliance for ships carrying dangerous goods and thus is not allowed to carry dangerous goods.

Voyage reports were analyzed in order to find out the most transported merchandises. The main cargo merchandises are fertilizers, rapeseed meals and pulpwood. However, forestry products together reach the highest quantity. Thus it is evident that this bulk carrier is strongly connected with the forestry industry. It is necessary to notice that after sawdust the washing and brushing of cargo hold are conducted but that usually does not postpone the departure significantly. The value of cargo does not have importance to the voyage speed, but it is usually object that the ship arrival and departure times are optimal to all interest groups. In optimal situation, the ship arrives out of the rush hour and is discharged and/or loaded before weekend or other holidays.[2]

2.2 Fuel

Historically, ships have been using many kinds of different fuels. Today heavy fuel oil and marine diesel oil are the most used. The environmental laws keep tightening up and the use of HFO is more and more restricted worldwide and the current trend is to put the focus on the air emissions of ships rather than on the emissions generated during the refining phase; refining a purer fuel creates more emissions and requires more energy in the refineries. Many kinds of alternative energy sources are investigated to cut down the emissions and to improve the efficiency rate. LNG and fuel cells are probably the most prominent at the moment but the sky sails and solar power have also been researched.

At sea M/S Belland uses marine diesel oil, which is a standard fuel in maritime traffic in the BSR. Even when the engine is 25-year old, it is capable of running with a wide range of fuels, including MDO. The MDO contains small amount of sulphur which is favorable for lubrication. MGO fuel without sulphur does not create problems as far as viscosity remains in acceptable range. Sometimes, GO is used during the sea voyage when MDO is not available. In that case the overall cleanliness of engine room is better and the fuel separators need less manual cleaning, which also improves the crews' working conditions.

It is common that the fuel consumption in road transport is better monitored with real-time data. Many ships, especially older ships, have only a manual gauging. M/S Belland fuel balance is measured two times a day so the overall consumption is well known, but the real time consumption with different load profiles cannot be accurately observed.

The weather affects significantly with the fuel consumption. Different seasons make the maritime traffic harder in the Baltic Sea Region than in many other parts of the world. Winter offers its own difficulties, and usually during hard ice conditions the full amount of ballast water is used. Ballast water is also needed in the summer when the cargo hold is full and the nature of cargo (total weight) impairs the stability of the ship. Then the bottom ballast water tanks need to be filled to lower the center of gravity so the required stability can be attained. Unfortunately, the voyage reports do not provide weather data.

2.3 Docking

According to current regulations, the docking has to be done two times in 5 years and maximum time between two dockings is 3 years. Usual procedures in dry docking are the washing of ballast water tanks and cleaning of the hull from different maritime organisms. Anti-fouling painting is also usually carried out if it is necessary.

2.4 Underwater hull

The underwater hull should be as smooth as possible though they are always somewhat rough. The roughness and adhered shellfish and algae increase the friction and this way more energy has to be used to move the ship thus increasing the fuel consumption as shown in table 3.[3] The economic importance of underwater hull condition cannot be neglected. Any increase in underwater hull roughness will result in a significant rise in vessel operating costs.

Figure 3. Weed in hull[4]

The roughness of the hull can increase the fuel consumption up to 40 % as the above table 3 shows. The fouling of hulls cannot be realistically totally avoided so small amount of friction reduction is usually tolerated. Among biological fouling different coating conditions (cracking, detachment, and touch-up repairs) influence hull roughness.

Table 3. Fouling and friction

Type of fouling	Increase in drag
Slime	1-2 %
Weed	up to 10 %
Shell	up to 40 %

Figure 4. Detachment in coating increase the hull friction[5]

2.4.1 Fouling management

A usual procedure in dry docking is the cleaning and washing of the underwater hull and painting an antifouling coating. Sometimes it is necessary to paint the whole underwater hull but many times only the areas where the previous painting has eroded are painted. Cleaning can also be carried out by a diver with a special piece of equipment (see Figure 5).

Figure 5. Diver performing hull cleaning

There are two FRC technologies available: silicone and fluoropolymer. Both these products do not use biocides to control fouling but rely on the making of a “non-stick” surface to make it difficult for fouling to adhere. Their advantage is also in no releasing of biocide into the environment.

3. ROUTES

Due to the fact that M/S Belland is a bulker, it has a huge variation in ports. In order to find out a typical route approximately one year's voyage reports (24.2.2010 – 28.1.2011) were analyzed and mathematical average was calculated to find out an average distance, speed, cargo weight etc. However, the mean values cannot be automatically compared with one another because the weather, the season and the type of cargo alternate. Thus it was found out that M/S Belland navigate primary in the BSR and its voyages are relatively short.

The utilization rate of M/S Belland is high and it has to be noted that discharging and loading took approximately 3600 hours whereas the sea voyage took 2900 hours as shown in table 4. The phrase: "time is money" can be used in freight transportation. The optimal situation would be when the loading and discharging are done as quickly as it can be safely done so that the time used in ports is minimized. However, in many cases the time used in ports are dependent on the other interest groups (stevedores, suppliers etc.) and on the weather conditions.

Table 4.The overall time usage in different situations

Overall time usage		
Situation	Hour	%
Ballast sailing	1410	18
Loading	1641	21
Laden sailing	2914	37
Discharging	1988	24
TOTAL	7953	

4. ENERGY EFFICIENCY AND COST BENEFIT ANALYSIS

4.1 Background

The energy efficiency topics have recently raised more and more discussion in the shipping industry due to the both economic and environmental reasons. Formerly, the energy efficiency only concerned the mechanical energy used for propulsion and it was the economic factors that fostered the development of engines. Nowadays, energy efficiency is improved by taking into account different sources such as waste heat, electric consumption, incinerators and route planning.

M/S Belland has been under Meriaura shipping company for approximately one and a half year so a long term data was not found.

4.2 Energy consumption

Energy consumption depends on the situation of the ship (discharge, voyage in ballast) and on the weather and season (winter, wind, waves). The primary consumer of energy is the propulsion system. The overall fuel consumption is seen in Table 5.

4.2.1 Propulsion

Propulsion is the greatest energy consumer in bulk carriers and there are several ways to decrease its energy demand. Firstly, the optimal load rate, which is provided by the engine manufacturer, should be used. Periodical service work should be also carried out in time.

When sailing the electricity can be generated either by shaft generators with the constant RPM value of the main engine or it can be also generated by auxiliary engines.

Table 5. The overall fuel consumption in different situations

Overall fuel consumption		
Situation	MDO	GO
In ballast	264,2	18,4
Loading (port)		30,7
Sea passage	722,5	20,1
Discharging(port)		29,5
Total	986,7	98,7

4.3 Fuel expenses

One year's voyage reports were analyzed to find out the overall amount of consumed fuel. M/S Belland uses mainly MDO but sometimes HFO is used to maintain the good lubrication of the engine. The overall consumption is approximately 1100 tons of gas oil. The fuel expenses are strongly dependent on the type of used fuel and MDO's market price is higher than HFO's. Lubrication oil expenses

5. ENVIRONMENTAL ASPECTS

5.1 General

Every ship produces various amounts of emissions during its operation. The amounts to emission are dependent on the vessel type. The freight transportation, which is conducted by cargo vessels, the largest absolute amount of emission consists of the air emissions from the engines producing propulsion power whereas passenger vessels produce great amount of other wastes for example waste waters and garbage.

The nature and amount of emissions can be affected in the design and operation phase of a ship. As a rule, ships are designed and constructed to meet with the rules and regulations in force at the given time. Additional Class notations offered by classification societies promote more environmentally friendly shipping, but these are seldom sought, especially in freight transportation. However, the PR imago is more and more important for passenger shipping industry nowadays and these notations provide an advantage over rival companies.

All emissions produced on a ship are either treated or untreated and then discharged to the sea (waste waters), air (fuel emissions) or to a PRF (solid waste). In this thesis the emissions produced during the normal operation of a bulk carrier are spread in different categories and discussed separately.

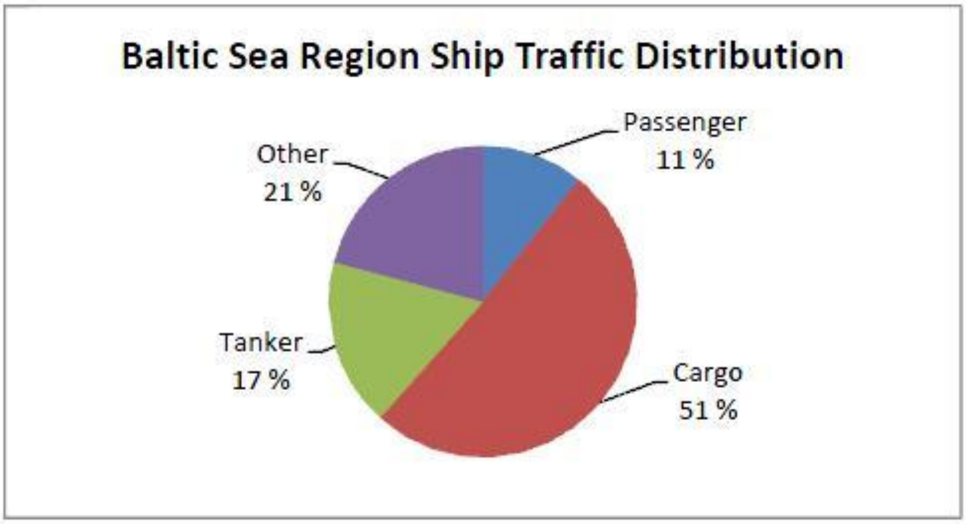

Figure 6. Maritime traffic distribution in the Baltic Sea Region in 2009[6]

The Baltic Sea Region is a very vulnerable ecosystem and the struggle to combat the growing pollution in the BSR is likely to become more challenging in the future when maritime traffic is expected to rise. The most severe problem in the Baltic is eutrophication and shipping has had a significant contributing effect on it. The passenger shipping which has a relatively high impact on the environment is only 11% in the BSR as shown in Figure 6. Cargo vessels constitute half of the maritime traffic so if all bulk carriers cut their emissions it would have positive consequences in this very vulnerable location.

The discharge of wastes is included in port fees in the BSR's ports.

5.2 Air emissions

The air emissions of the ship are different types of pollutants, including SO_x, No_x, CO_2, soot, water vapor, particles and residues of heavy metals. The amount of these substances is strongly dependent on the fuel used. The most worldwide used fuel is the HFO. HFO is a blend of different residues from various distillation processes and thus contains the very high concentrations of harmful substances. Therefore it is considered as toxic substance. M/S Belland uses mainly MDO and therefore her air emissions are relatively low but every once in a while it is necessary to use heavy fuel oil to maintain the good lubrication of the engine. The main engine is approximately 25 years old thus it was designed to work with heavy fuel oil whose parameters (viscosity, density etc.) are very different in compared with MDO and GO.

On the other hand, using environmentally friendly MDO, or other alternative fuels, whose prices are far higher than HFO’s, is more done than the current regulations require, can lead to a worse competition position compared with the competitors. In order to create a healthy and fair competition in maritime traffic, all companies should use the same type of fuel to make sure that any company would not have a distorted competitive advantage over others by using cheaper and more polluting fuel options. It is evident that the emission control regulations continue to tighten up in the future and global awareness for nature is increasing. Passenger shipping companies have already taken emissions and environmental aspects seriously some time to maintain a positive PR imago of sustainable business activity. It is very probable that the freight transportation companies also have to follow this progression.

5.2.1 SO_x

SO_x is under the most concern nowadays, mainly because it has a verified harmful impact on human health. It also causes acid rain and helps creating PMs. Particulate matters with soot causes serious health impact on people, exposing them to lung and heart diseases.

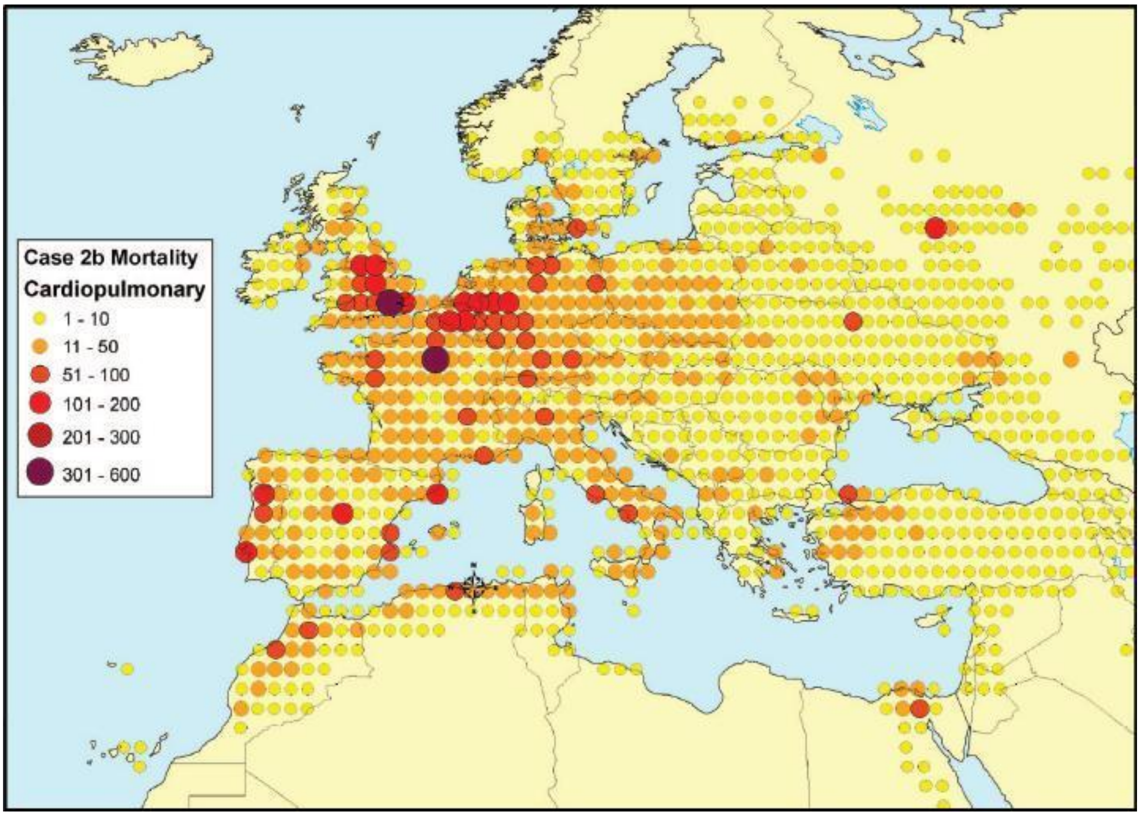

Figure 7. Annual cardiopulmonary mortality attributable to ship PM_{25} emissions for Europe and Mediterranean[7]

Figure 6 shows how the mortality connected with ship PM_{25} is relatively high around the biggest port cities, especially in London and Rotterdam region. The situation in Baltic Sea region is not yet as alarming. However, the capital areas of Finland and Sweden are also highlighted. PMs in arctic region speed up melting ice sheet because black particles cannot radiate the heat radiation of the sun as well as pure white snow do. The melting in arctic areas is a serious threat by many scientist and leads to the uprising of sea level. There are also economic interests in the arctic areas because of the natural resources (natural gas, oil) which are believed to exist under the seafloor.

Annex VI (MARPOL) regulations include caps on the sulfur content of fuel oil as a measure to control SO_x emissions and, indirectly, PM emissions (thus there are no explicit PM emission limits). Special fuel quality provisions exist for SO_x

Emission Control Areas (SO_x ECA or SECA). Table 6 shows the sulfur limits and implementation dates.[8]

Table 6. MARPOL Annex VI Fuel sulfur limits

Date	Sulfur Limit in Fuel (% m/m)	
	Sox ECA	Global
2000	1,50 %	4,50 %
2010.07	1,00 %	
2012		3,50 %
2015	0,10 %	
2020[a]		0,50 %
[a] - alternative date is 2025, to be decided by a review in 2018		

However, alternative measures are also allowed (in the SO_x ECAs and globally) to reduce sulfur emissions, such as through the use of scrubbers. The development of the reduction of emissions is predictable up to the year 2025 as Figure 8 shows. This development of tightening legislation will most probably increase the transportation costs which can significantly weaken the Finnish competitiveness as there are usually no other feasible options for freight traffic.

On the other hand, the issue of SO_x emissions is under debate. Some researchers have said that fuel with SO_x content alleviate global warming by creating particulate matters which assist clouds to develop. Clouds help radiate off heat coming to the planet and thus, at least, slow down the global warming. When thinking this way, it can be arguable to use heavy fuel oil when sailing in the oceans where health effects are not an issue.

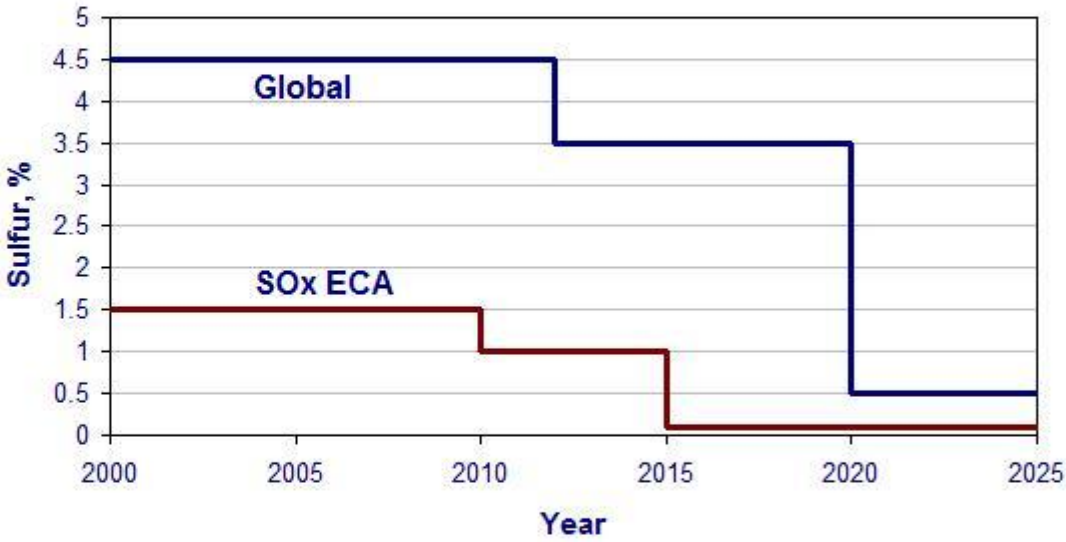

Figure 8. MARPOL Annex VI Fuel Sulfur Limits

5.2.2 NO_x

The NO_x emissions of ships have a local and regional impact on air quality. NO_x emissions are one factor of acid rains which has a severe impact on fauna. In addition, NO_x participate in ozone layer depletion thus this environmental impact is usually local. Eutrophication, which is the most serious problem in the Baltic Sea region, is significantly contributed by NO_x. NO_x also contributes to the formation of ground-level ozone, which damages vegetation as well as human health, and contributes to global warming. In 2000 approximately 800 000 square kilometers (60%) of the EU forest area were exposed to ozone concentrations exceeding the critical level.[9]

The development of NOx emissions and its prognostication up to the year 2020 are shown in Figure 6. EU27 means emissions from land-based sources in all EU countries (including domestic shipping). The Sea means emissions from international shipping in European sea areas. The TSAP (Thermatic Strategy on Air Pollution) is the target in line with the EU from September 2005 and IMO is expected outcome from implementing the preliminary IMO-agreement from April 2008. Table 7 shows that NO_x emissions are a major concern in the Baltic Sea Region and are strong factor in eutrophication.

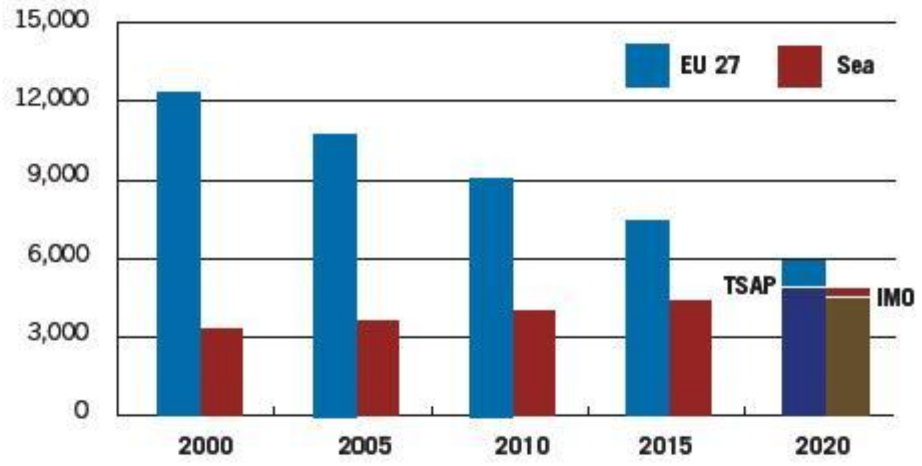

Figure 9. Emissions of NOx 2000-2020 (kilotonnes)[10..]

Table 7. The proportion of air pollutant depositions of sulphur and nitrogen oxides from shipping in European countries[11]

Country	Sulphur	No_x-nitrogen
Denmark	45 %	27 %
Sweden	23 %	22 %
Netherlands	21 %	18 %
UK	19 %	19 %
Ireland	18 %	20 %
France	12 %	14 %
Finland	12 %	14 %
Belgium	12 %	13 %
Italy	11 %	17 %
Germany	10 %	10 %

5.2.3 CO_2

CO_2 is certainly the best known emission in public. CO_2 causes global warming which has many severe effects all around the world. Due to the effectiveness of transferring freights by ship, in comparison with air transportation, the CO_2 per freight ton is relatively low. Probably for this very reason the CO_2 emissions from global shipping have not been an issue for major concern.

5.2.4 Possibilities to reduce air emissions

As mentioned in the previous chapters the fuel used has the major impact on the both quantity and quality of air emissions. When changing the HFO to an alternative fuel, most air pollutants can be either reduced or totally eliminated. This can be concerned as a preventative mean. There are also many technically realistic possibilities, for example handling the exhaust gases with catalytic converters and using the scrubbers, to reduce air emissions produced by a diesel piston engine of the ship. M/S Belland uses MDO which is a clean option and therefore her air emissions are relatively low.

The most commonly used marine fuels and their emissions are presented in Table 8. NOx emission values are estimations. LNG provides the cleanest and most prominent option for the future ships by cutting the emissions to near zero.

Table 8. Alternative fuels and their emissions[12]

Fuel		HV [MJ/kg]	Density [kg/dm^3]	Carbon Factor	Sulfur [% m/m]	HV/Vol. [%]	CO_2 [%]	SO_X [%]	NO_X est.
Heavy Fuel Oil	IFO-380	40,4	0,991	3,114	3,5	ref	ref	ref	ref
Heavy Fuel Oil	IFO-180	40,5	0,991	3,114	3,5	100	-0,2	-0,2	0
LS Heavy Fuel Oil	LS-380	40,4	0,991	3,114	1	100	0	-71,4	0
LS Heavy Fuel Oil	LS-180	40,5	0,991	3,114	1	100	-0,2	-71,4	0
Marine Diesel Oil	MDO	41,5	0,92	3,151	1	95	-1,6	-72,2	-6
Marine Gas Oil	MGO	42,7	0,865	3,206	0,1	92	-2,6	-97,3	-6
LNG	LNG	51,3	0,45	2,75	0	58	-30,5	-100	-85
Biodiesel 100%	B-100 S15	37,5	0,88	3,1	0,0015	82	7,2	-100	10
Biodiesel 100%	B-100 S500	37,5	0,88	3,1	0,05	82	7,2	-98,5	10
Biodiesel 20%	B-20 S15	41,5	0,858	3,1	0,0015	89	-3,1	-100	2
Biodiesel 20%	B-20 S500	41,5	0,858	3,1	0,05	89	-3,1	-100	2

5.3 Solid waste

Different ships produce different amounts of solid waste. Solid waste contains waste products in the past were made from natural and biodegradable materials. Nowadays many synthetic materials are used, due to their good quality, durability and low price and their disposal has become a multifaceted problem. The sea dumping of wastes can be not only harmful to marine wildlife but also visually annoying when the archipelago and coasts are littered. Certain products, for example plastic which is not biodegradable, are very problematical and life-threatening to many animals. Plastic wastes are eaten by birds and fish, but they are unable to digest it, which causes them to die to starvation to death with their stomachs full. In addition, harmful substances can find their way up from a trophic level to another up to the human.

Table 9. Descriptions and examples of different types of solid waste

Type of Solid Waste	Examples and Descriptions
Cardboard	Dunnage (lining and packaging materials that float) and cardboard from all manner of packaging materials
Paper	Paper and packaging
Plastic	Synthetic ropes, plastic containers, plastic bags, biodegradable plastics, poly-ethylene terephthalate plastics and high density polyethylene plastics
Wood	Wood pallets and waste wood
Glass	Chipped or broken glasses, food and beverage jars, bottles
Metal cans	Aluminum soft drink cans, tin cans from the galley, steel cans from ship maintenance operations
Food waste	Waste derived in whole or in part from fruits, vegetables, meats, or other plant or animal material (includes food scraps, table refuse, galley refuse, food wrappers or packaging materials contaminated with food residue)
Incinerator ash	Ash generated from the incineration of packaging materials, paper and cardboard wastes, etc.
Food wrappers and packaging	Paper and plastic wrapping/packaging materials with food residue

The absolute amount of waste generated by ships varies from ship to another, according to their size, a number of passengers and crew, and consumption of materials. Cruise ships generate a relatively high amount of different wastes compared with other types of vessels. Due to this fact, the best results in reducing waste loads can be achieved in passenger ships. This can be met by promoting the usage of environmentally friendly, for example biodegradable and less natural resource consuming, packaging materials and the less usage of packaging material. As the consumers become more and more environmentally aware, the greater part of the PR image of the shipping companies has to consist of environmentally sustainable values.

5.3.1 Non-hazardous

Non-hazardous waste by its name can evoke an image of environmentally friendly products and wastes but in fact they can have a huge negative impact on the whole ecosystem. For example, food waste dumped to The Baltic Sea contributes to the eutrophication and can disturb the local marine wildlife providing to them a type of food that they are not used to.

In this case, the absolute amount of produced solid waste (for example, food waste) is significantly high in large passenger vessels. Other commercial vessels, for example bulk carriers and container ships, produce much less waste. The problem can be handled either onboard or ashore.

5.3.2 Hazardous

Hazardous wastes have a serious threat to the environment. They usually contain flammable, toxic, corrosive or reactive substances which exist in solid, liquid and gas forms. The usual origin of these wastes is used light bulbs, expired medicals, used batteries, used oil and fuel filters etc.

The absolute amount of produced hazardous waste varies strongly due to the nature and size of the ship. In the case of cargo vessels, the amount of hazardous waste is relatively small and there is therefore a good way to handle them by storing it onboard and discharging to a PRF. It has to be made sure that there is enough convenient space for conserving the hazardous waste when the offshore periods can be quite long.

There are only a few ways to reduce the environmental impact of solid waste. The main means are waste minimization, sampling along with waste stream management and efficient recycling.

5.4 Gray water

Gray water consists of wastewater from sinks, showers, galleys, laundry and cleaning aboard a ship. The source water for most gray water sources is potable water (see Table 11). It contains different cleaning agents and impurities which are harmful to marine environment. Gray water may also have other pollutants as oils, lubrication residues and sewage. Many cleaning agents contain phosphorus which contributes to eutrophication. The amount of gray water is relatively high in cruise vessels and passenger ferries.

Table 10. Description of gray water definition from different sources[13]

Source	Gray water Definition
Clean Water Act, 33 U.S.C. 312 (a)(11)	Galley, bath, and shower water
International Maritime Organization Guidelines for Implementation of Annex V of MARPOL (Sec. 1.7.8)	Drainage from dishwasher, shower, laundry, bath and washbasin drains and does not include drainage from toilets, urinals, hospital and animal spaces, as defined in regulation 1(3) of Annex IV, as well as drainage from cargo spaces
Title XIV - Certain Alaskan Cruise Ship Operations, 33 U.S.C § 1901 Note (Sec. 1414(4))	Only galley, dishwasher, bath and laundry waste water
Coast Guard regulations imlementing MARPOL and the Act to Prevent Pollution from Ships, 33 CFR 151.05	Drainage from dishwasher, shower, laundry, bath and washbasin drains and does not include drainage from toilets, urinals, hospitals, and cargo spaces

Table 11. Common sources and characteristics of gray water[14]

Water source	Characteristics
Automatic Clothes Washer	Bleach, foam, high PH, hot water, nitrate, oil and grease, oxygen demand, phosphate, salinity, soaps, sodium, suspended solids, turbidity
Automatic Dish Washer	Bacteria, foam, food particles, high PH, hot water, odor, oil and grease, organic matter, oxygen demand, salinity, soaps, suspended solids, turbidity
Sinks, including kitchen	Bacteria, food particles, hot water, odor, oil and grease, organic matter, oxygen demand, soaps, suspended solids, turbidity
Bathtub and Shower	Bacteria, hair, hot water, odor, oil and grease, oxygen demand, soaps, suspended solids, turbidity

5.4.1 Management

Gray water is usually discharged to the sea. Recent years the PR imago of the ecological values of shipping companies has become more and more important, and many new cruise vessels are equipped with the waste water management system.

Discharging the gray water to the sea can be either done treated or untreated. Cargo ships produce relatively small amount of gray water and it is usually untreated or treated just to meet the minimum standards and regulations.

Holding tanks provide opportunity to maintain the gray water instead of discharging it to the sea. A typical gray water piping system may lead to several gray water holding tanks segregated by gray water source. Sometimes, gray water sources may undergo limited treatment enroute to the holding tanks (for example, gross particle filters or grease traps). Gray water from holding tanks can be lead to AWTs for treatment, discharged immediately upon generation or diverted to longer-term storage in one or more double bottom holding tanks for controlled discharge.

5.5 Bilge water

Bilge water is the mixture of water, oily fluids, lubricants, cleaning fluids and other similar wastes. Its primary sources are the main and auxiliary engines, boilers, evaporators and other mechanical and operational sources found in the machinery spaces of a ship thus machinery needs oils, lubricants and hydraulic fluids to work properly. It is common on ships for oil or water to leak into the bilge from these sources. It is impossible to prevent them from getting in contact with seawater cause they are used virtually everywhere in the ship. A good example is the underwater propeller which is sealed by oil lubricated shaft seals.

However the main source of oil spills to the sea is the mixture of oil and water originated from bilge. Bilge water forms when the ship operates, for example from condensation and air conditioning. There are usually various small leaks in machinery during routine maintenance operations.

Oily bilge can be treated with a special piece of equipment called the oily water separator (OWS), but still each year 20,000 – 70,000 tons of oil is discharged to The Baltic Sea without treatment.[15] This will result in around 100 000 – 500 000 dead birds annually. The reasons for these incidents are multiple, but usually it is a faulty and conscious bypass of OWS in contravention of maritime pollution regulations. Bilge water is the most common source of oil pollution from cruise ships.[16]

5.5.1 Management

Fortunately there are many technical solutions to handle the preceding problem. A realistic option is to store the bilge into holding tanks and then discharging it to PRF. Naturally, the amounts of bilge and sludge produced onboard tend to fluctuate, depending on the size and nature of the ship, machinery arrangement and operation. For this reason it is reasonable to concentrate on the treatment methods than on the absolute amounts of sources. However, the engine manufacturers have been developing technical solutions to reduce the consumption of lubrication oils.[17]

There are two options to handle with the bilge water: holding tanks and discharging to PRF. Untreated bilge water and sludge can be stored in the holding tanks and discharged to PRF. However, there are some drawbacks in the storing; the capacity of the tanks has to be dimensioned according to the duration of voyage, which requires space and thus results in loosing cargo volume. Another factor is that the amount of produced bilge and sludge can be significant therefore the charge for discharging the waste to PRF can be remarkable. Even if there are better possibilities to create the sewage treatment facility onshore, its performance for waste treatment can be inadequate due to the complicated chemical nature of the waste water.

5.6 Black water

Black water contains numerous harmful viruses, bacteria and nutrients. It may also contain other potentially toxic substances, for example pharmaceuticals. If black water is discharged to the sea untreated, it precipitates euthropication, distributes pathogens and causes the viral contamination of fisheries and shellfish beds.

5.6.1 Management

Multiple possibilities to handle the waste water exist. The most common methods are the discharge to the sea and holding tanks.

By far the easiest method of handling black water is to discharge it directly to the sea, in case the local regulations permit such action. This option is the cheapest but environmentally very unfriendly option though the absolute number of harmful substances in small carriers is quite insignificant.

The other method is using the holding tanks to store the black water onboard and then discharging it to a port reception facility (PRF). This is a feasible option for small ships on short voyages, but unfortunately realistically impossible for large passenger ships that are designed to be autonomous for weeks on the sea. The raising environmental consciousness of passengers forces shipping companies to pay attention to this issue as a PR imago question.

Hold tanks require cargo space though the optimal volume depends on the crew number. Discharging the waste waters to PRF’s does not increase the operational costs of the vessels because port charges in the BSR include the discharge of ship-generated waste, allowing avoids the investment and maintenance costs of the waste water treatment plan. It is technically far easier to create an efficient black water management facility ashore.

5.7 Ballast water

Ballast water is usually taken on in coastal water and discharged at the next port. Large tankers, bulk carriers and cruise ships use a huge amount of ballast water and they operate long, often intercontinental, routes. Ballast water usually contains a great variety of biological materials, including plants, viruses, animals and bacteria. During the voyage, the temperature chances and lack of food and light kill many, but not all of these organisms. The survived organisms establish populations in the surrounding waters and thus interfere with the original ecological system. This ballast water can have a negative impact on the whole marine environment.

Recent years more pressure has been put on to the treatment of ballast water due to the observation of negative impacts. There are several means of decreasing the negative effects of ballast water discharge, including changing the ballast water during the voyage several times. Specific ballast water treatment equipment has been developed.[18]

M/S Belland operates only in the Baltic region and has a small amount of ballast water thus the ballast water issue is not important in this thesis.

5.8 Oil spills

There are various reasons for illegal oil spills in the BSR such as the lack of bilge water filtration equipment and attitudes. The illegal oil discharges have been observed with aerial surveillance (see Figure 10) and it is noticed that they are not only at the surroundings of coastal towns but also in the middle of the sea. Not only being toxic to marine life the components, such as polycyclic aromatic hydrocarbons (PAHs), in crude oil are difficult to clean up, and last for years in the sediment and marine environment. [19]

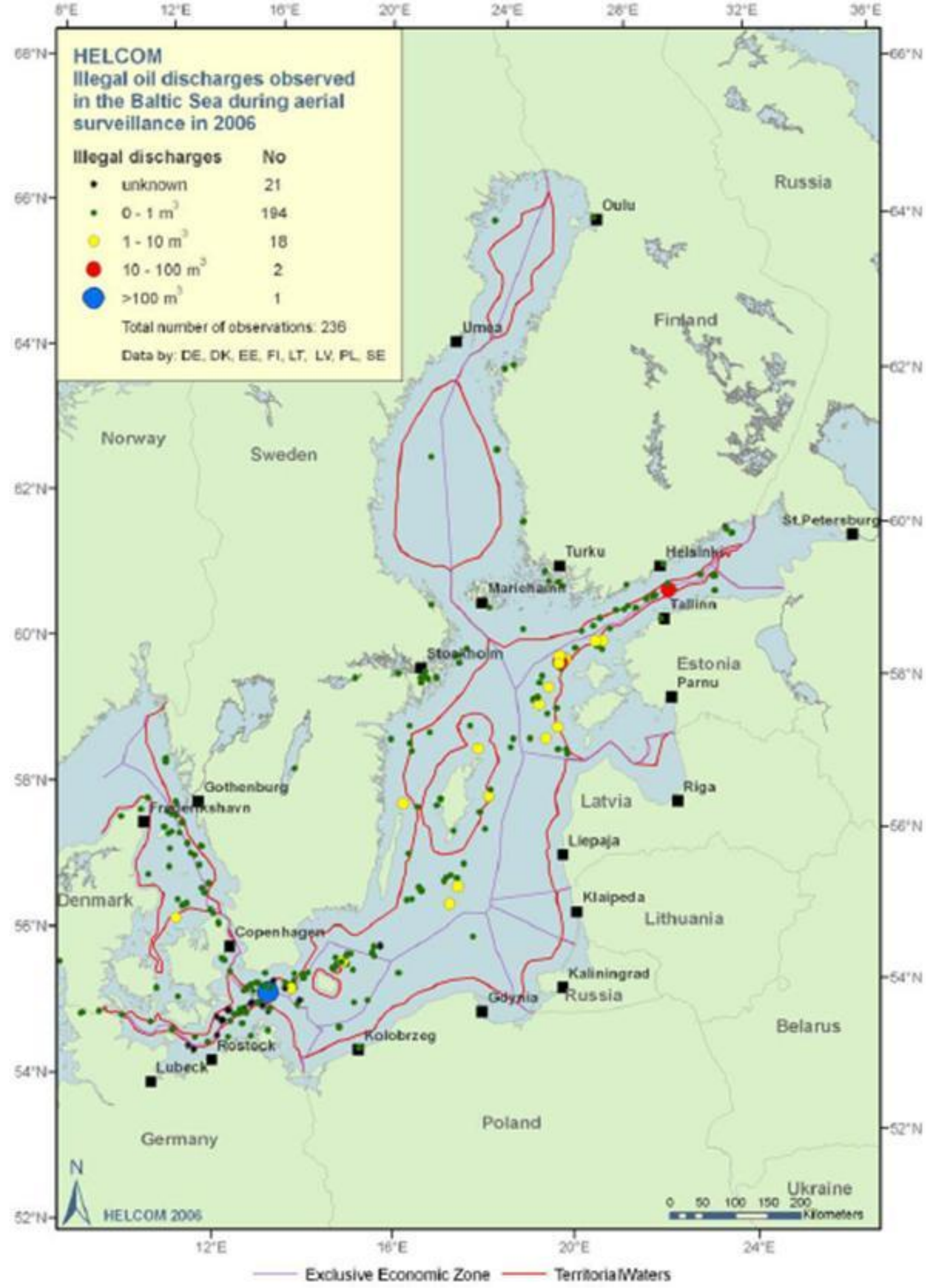

Figure 10. Location of the oil spills observed in the Baltic Sea Area in 2006[20]

Even when the traffic has increased in the BSR the downward trend of oil spills has been acquired as seen in Figure 11.

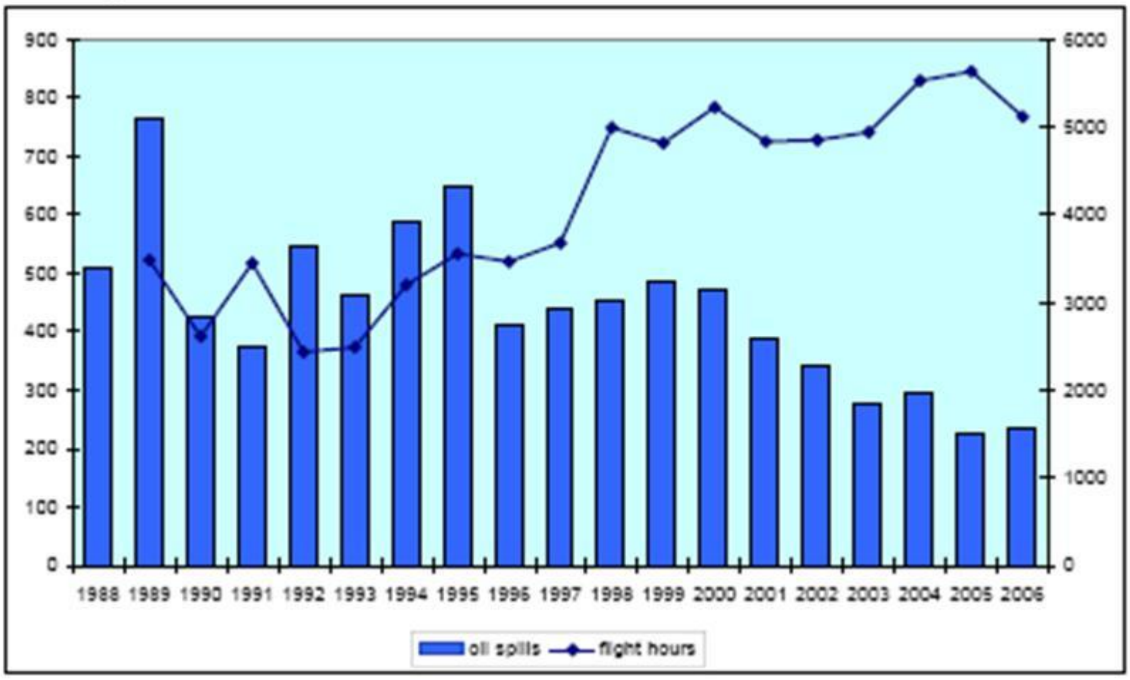

Figure 11. The total number of flight hours and observed oil spills in the HELCOM area during 1988-2006

5.9 Cold ironing

Cold ironing, also known as shore-side power, does away with the need for burning fossil fuel altogether on board when the ship is in harbor and equipped with the needed equipment. In cold ironing, ships visiting ports are connected to local grid power sources which are usually already regulated by local pollution norms. This energy source serves the handling machinery and hotel requirements of the ship. As mentioned before, some cargoes may need drainage, refrigeration etc. In this case, all generating sources are shut down and the ship is hence cold ironed. Figure 12 shows the basis of cold ironing.

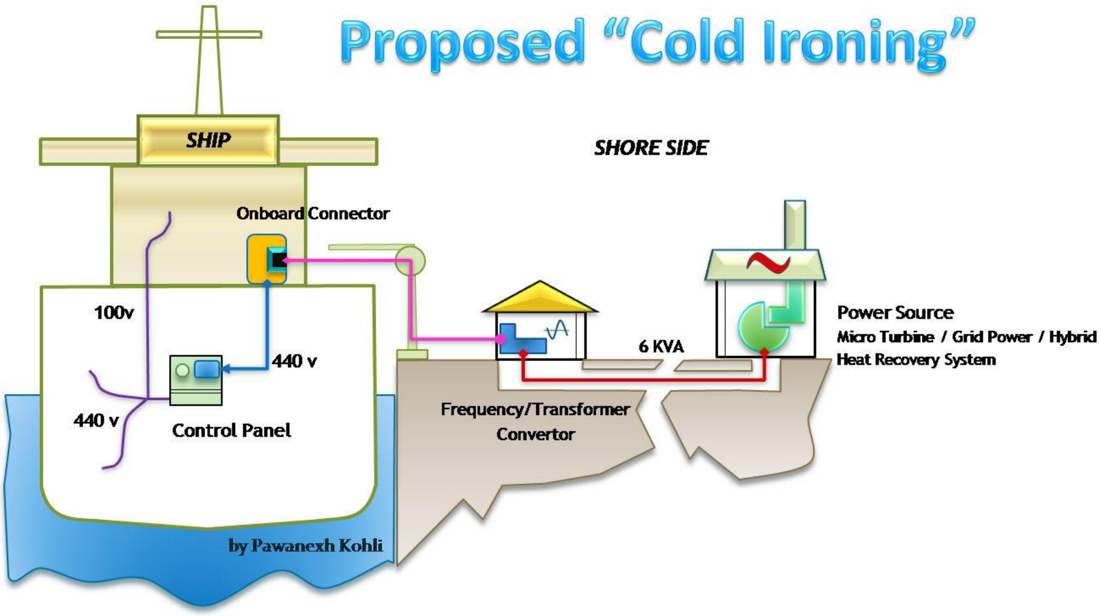

Figure 12. Basis of cold-ironing

However, there are some concerns and problems with the cold ironing. Firstly, the compatibility of the main electricity parameters is a major issue. Ships have been built in various yards all over the world and for that reason they do not have a uniform voltage and frequency requirement. Main two parameters are 220 volts at 50 Hz and 110 volts in 60 Hz. Primary distribution voltage can vary from 440 V to 11 kV. In M/S Belland's case this would not be an issue, because the ship operates in Baltic region in which the first mentioned parameters are used. Secondly, requirement load capacity varies from ship to ship. It ranges from a few hundred kW in case of car vessels to a dozen or more MW of a reefer-, or passenger ships. The third challenge is that connectors and cables are not internationally standardized though development work has progressed in this direction.[21]

5.9.1 Comparison between the ship's own generator and cold ironing

As the energy can be produced by the ship's own generator or it can be taken from ground the emissions vary. As the emissions of the ship's own generator can hardly be significantly reduced the cold ironing becomes a more interesting option. Emissions from cold ironing are dependent upon how the energy is produced, because there are several possibilities for it on ground. The ships energy demand plays a significant role when contemplating cold ironing and it has to be noted that the ship's own generators always produce ”extra” energy.

The cold ironing produces emissions, but the source of emission is usually far away from the port and housing areas. Moreover onshore power plants have better options to reduce and handle the emissions. The healthy issues support the cold ironing vis-à-vis the ship's own energy production. However, most commercial ports do not support cold ironing but it is still a realistic option to become general in the future.

Table 12. One year's port consumption of GO for energy production

Overall consumption (GO)	
Loading port	30,7
Discharging port	29,5
Total	60,2

Table 12. shows the total amount of consumed GO in port situations which is relatively low so the cold ironing is not a feasible option. On the other hand, the cold ironing could be the case if the ship already had a good cold ironing equipment which would also be compatible and supported by visited ports.

5.10 Anti-fouling

The use of antifouling products in the BSR is particularly problematic in pleasure boats for 4 reasons. Firstly, the impacts of boating are focused mainly on coastal waters, which is the area of reproduction of many aquatic organisms. Secondly, the emissions from antifouling paints are at their highest during the most sensitive period in the reproductive cycles of these species. Third reason is that the pleasure boats usually stay in the port most of their time resulting in high local environmental impact. Levels of harmful substances, such as copper and triazines, have been measured in pleasure boat marinas on the Swedish coast. [22]

In addition, the sensitive usage of antifouling products is also severe issue because the BSR is such a vulnerable ecosystem. This is due to the young age and low species diversity as well as the slow turnover rate and low volume of water. Due to the low number of species in the Baltic Sea, a few species are so called "key species" that play an important role in the entire ecosystem. The active substances of antifouling products are detrimental to two important key species of the Baltic Sea, which are bladderwrack seaweed and blue mussel.

There are various alternative anti-fouling systems which all have their own benefits and disadvantages which are introduced in Table 13.

Table 13. Alternative anti-fouling options and their advantages and disadvantages.[23]

Product/method	Advantages / disadvantages
Copper-based antifouling paints	Already exist and less toxic than TBT in aquatic environment. Only effective against marine fauna - to combat weed growth, herbicides are added which may pose new threats to environment.
Tin-free anti-fouling paints	Have proved adequate on passenger ferries in North Sea. Work best on vessels that go to dry dock every three and a half years or more frequently because some fouling does occur. Works on special purpose vessels such as tugs, pilot boats, lifeboats and research vessels if these are used at least 100 days per year and go into dry dock at least every three years. When use is not as frequent they run more risk of fouling and will need dry dock every year.
Non-stick coatings	Contain no biocide but have extremely slippery surface – preventing fouling occurring and making it easier to clean when it does. Most suitable for vessels with minimum speed of 30 knots. Damage to coating difficult to repair. Light fouling occurs but easily removed with high-pressure hose in annual dry dock visits.
Cleaning	Periodic cleaning of hull is most appropriate for ships operating in both sea and fresh water and in areas where few organisms attach to hull. Cleaning of merchant ships involved divers using rotating brushes or high-pressure hoses.

Natural resistance, natural biocides	Substance produced in nature which prevent fouling or hinder fouling process - based on capacity of marine organisms such as corals and sponges to remain free of fouling. Research on use of natural compounds is in early stages, but active metabolites (for example ceratinamine and mauritiamine) have been identified and new biocides have been synthesized. Enzymes can break the sticking of bacteria (the first phase of fouling's growth) to the hull; while the concept of hydrophilic coating has been inspired by the preference of fouling to stick to hydrophobic surfaces, such as rocks and vessels. The organisms have no grip on hydrophilic 'wettish' surfaces. Paint industry and research institutes are involved in Camellia project (running 1996-2000), subsidized by EU, to research use of natural compounds.
Electricity	Creating a difference in electrical charge between the hull and sea water unleashes chemical process which prevents fouling. This technology shown to be more effective than tin-free paint in preventing fouling, but system is easily damaged and expensive. Also creates increased corrosion and higher energy consumption.
Prickly coatings	Includes coatings with microscopic prickles. Effectiveness depends on length and distribution of prickles, but has been shown to prevent attachment of barnacles and algae with no harm to environment. However, prickles could increase water resistance of vessel. Use of prickly surfaces on static objects such as buoys and cooling water inlets seen as realistic option in near future.

An optimal biocide for use in an anti-fouling system has the following characteristics: low water solubility, no bioaccumulation in the food chain, low mammalian toxicity, not persistent in the environment, compatibility with paint raw materials. Moreover, it should have favorable price-quality ratio.

6. CONCLUSIONS

6.1 Applicability of results

This research concerns an 80's-bulk carrier which operates in the Baltic Sea Region however some points of view in this thesis can be extrapolated to all types of ships.

6.2 Extra research issues

A lot of research has to be done to find ways to meet with the future environmental regulations. Explicit guidelines should be provided long enough before the new laws and regulations come into force. Nowadays, most prominent technologies are gas engines (ship engines that operate on natural gas (LNG) and thus reduce SO_x emissions to near zero), shore-side electricity and alternative energy sources. Experiments with wind power (skysails) and fuel cells are also conducted.

7. SUMMARY

The main aim of this thesis was to develop a model for evaluating the environmental impacts of ships. The thesis is mainly descriptive by its nature and it provides a tool when developing different efficiency, both environmental and energy, indexes. As the M/S Belland operates in the Baltic Sea Region, particular attention was put on the emissions which have the greatest environmental impact in this area. The energy consumption research of M/S Belland provides a convenient tool for the future theses.

As a way to understand the background and current environmental status of BSR various legislations, laws, rules and previous reports were studied. Interviews of professionals of their own field (biology, marine traffic etc.) were helpful to gain information and to concentrate on the particular important issues.

By studying the newest technologies, it was noted that modern ships could be more environmentally built with today's technology as they are but the economic motives are so strong that the ships are built only to meet the current regulations. It was noticed that older ships can reduce their emissions with relatively easy means, for example with changing the fuel and with a route planning. However M/S Belland has already done almost "everything that is possible" and most options to improve its energy efficiency and reduce its environmental impact are not financially realistic.

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