Reducing the carbon footprint at Wärtsilä Fuel Gas Supply Systems – Nordic logistics route analysis related to new rail link to China

Emanuel Björk

Master's thesis
Supervisor: Cecilia Edsvik, Wärtsilä
Examinator: Prof. Margareta Björklund-Sänkiaho
Energy Technology, Vasa
Study programme in Chemical Engineering
Faculty of Science and Engineering
Åbo Akademi University
May 3, 2019

ABSTRAKT

Flytande naturgas har blivit ett allt mer populärt bränsle för marina fartyg. Orsaken bakom tillväxten är huvudsakligen de nya inkommande utsläppsreglerna som kommer förbjuda användningen av bränslen som har en svavelhalt på över 0,5 %. Flytande naturgas möter de nya kraven och har även andra miljöfördelar jämfört med marin diesel.

Fuel Gas Supply Systems-avdelningen vid Wärtsilä levererar bränslesystem för gas till den marina marknaden. På grund av den ökade efterfrågan säljs fler produkter vilket resulterar i fler transporter till tillverkare i Kina.

Utsläppen av växthusgaser från transportsektorn bidrar till den globala uppvärmningen. I enlighet med Parisavtalet är målet att begränsa den globala uppvärmningen till 2 °C över den förindustriella nivån. Därför finns ett behov av att minska på utsläppen från transporten och övergå till mer hållbara fraktmetoder.

Målet med detta arbete är att undersöka vilken som är den bästa fraktmetoden för avdelningen Fuel Gas Supply Systems, genom att ta i beaktande miljöpåverkan, kostnader och leveranstid. En rekommendation på hur man kan sänka kolidioxidavtrycket kommer presenteras tillsammans med utsläppsberäkningar över de totala utsläppen för avdelningen 2018.

Ett förslag på vidare forskning är att analysera om det är rimligt att ha en mer central konsolideringspunkt för komponenter någonstans i centrala eller södra Europa. En ny utsläpps- och kostnadskalkyl kunde utföras utgående från detta exempel.

Nyckelord: Utsläpp, frakt, LNG

ABSTRACT

Liquified natural gas is becoming a more common fuel option for marine vessels. The reason behind this growth is mainly due to coming environmental regulations that will ban ships from using fuels with a sulphur content above 0.5%. Liquified natural gas can meet these requirements and has other environmental benefits when compared to marine diesel.

Fuel Gas Supply Systems is a department at Wärtsilä which supplies fuel gas systems for the marine market. Due to the increase in demand, more products are being sold, which has resulted in an increase in transports to manufacturers in China.

Emissions of greenhouse gases from the transportation sector are contributing to global warming. In accordance with the Paris Agreement, the aim is to limit global warming to 2 °C over pre-industrial levels. Accordingly, there is a need to reduce emissions from transport, and switch to more sustainable transportation methods.

The task of this thesis was to find out which freight method is most suitable for the Fuel Gas Supply Systems department. This was achieved by taking environmental impacts, costs and delivery time into consideration. A recommendation on how to reduce the carbon footprint was to be presented together with calculations of the total emissions from freight within the department in 2018.

As a result, the total emissions and costs for each freight method have been calculated. Based on the calculations and the theory chapter, the most suitable freight method has been recommended together with a recommendation on how to reduce the carbon footprint.

A recommendation for further research is to analyse if it is practical to have a more central consolidation point for components, somewhere in central or southern Europe. A new emission and cost analysis could be made based on this example.

Key words: Emission, freight, LNG

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to thank Mathias Janson for giving me the opportunity to write my thesis for FGSS and combine the thesis work with full-time work. A special thanks to my supervisor Cecilia Edsvik for supporting me through my thesis work and providing me with valuable insights and expertise. I would also like to thank the whole Fuel Gas Supply System team for assisting with valuable knowledge and creating a fun and pleasant workplace.

Additionally, I would like to thank my Professor, Margareta Björklund-Sänkiaho, for her help and support with my thesis and for her work during my studies. My classmates also deserve a special thanks for making my studies much more enjoyable.

Finally, I would like to thank Demi-Rose Norton for all her great support from home.

Emanuel Björk

May, 2019

Vaasa, Finland

LIST OF SYMBOLS AND ABBREVIATIONS

Bar (g)	Bar gauge – expressing the pressure in relation to atmospheric pressure
CH_2O	Formaldehyde
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CFCs	Chlorofluorocarbons
CH_4	Methane
FCL	Full container load
FGSS	Fuel gas supply systems
GHG	Greenhouse gas
GVU	Gas valve unit
GWP	Global warming potential
H_2	Hydrogen
H_2O	Water
HA	Hectare
HFCs	Hydrofluorocarbons
HFO	Heavy fuel oil
IMO	International Maritime Organization
IPPC	Intergovernmental Panel on Climate Change
LCL	Less than container load
LNG	Liquified natural gas
MDO	Marine diesel
N_2O	Nitrous oxide
NO_x	Nitrogen oxides

O_2	Oxygen
O_3	Ozone
Pb	Lead
ppm	Parts per million
SF_6	Silicon tetrafluoride
SO_x	Sulphur oxides

1 INTRODUCTION

1.1 Background

Liquified natural gas (LNG) has long been seen as the future of marine fuel, however, it has been difficult to predict exactly when that future will arrive. The growth of LNG-driven ships has been slower than expected, and DNV GL (Det Norske Veritas and Germanischer Lloyd) has lowered their estimate from 1,000 LNG-driven ships to 400-600 LNG-driven ships expected to sail the seas in 2020. Even though the estimate has been reduced, the market is now starting to take off. The reason behind this growth is mainly coming environmental regulations, but the fluctuating oil price has also made shipowners seek other fuel options. Investments are furthermore being made in bunkering infrastructure. There are 60 supply locations worldwide and it has been decided that 28 more are to be built in the coming years, according to Wold (2017).

Maritime transport is responsible for around 2.5% of the world's greenhouse gas emissions. It emits approximately 1,000 million tons of CO_2 each year. In 2020 the International Maritime Organization (IMO) will implement rules that will ban ships from using any fuels with a sulfur content above 0.5%. In April 2018, the IMO also adopted an initial strategy where it was agreed that the total GHG emissions are to be reduced by 50% by 2050. (IMO 2018)

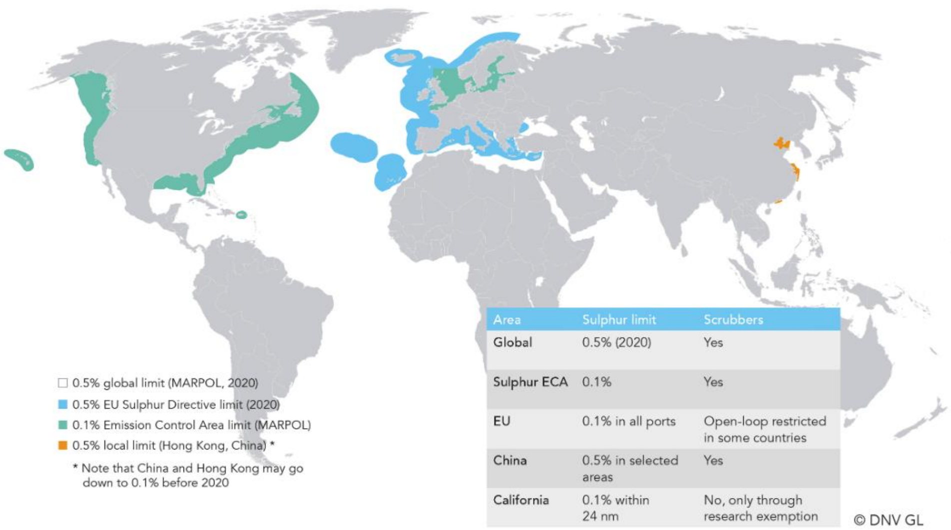

Figure 1. A map showing the future sulphur emission regulations in the world. (Sollied, 2019.)

Natural gas as a fuel has compelling environmental advantages over heavy fuel oil (HFO) and marine diesel (MDO). As a comparison, LNG emits 25% less carbon dioxide (CO_2), 90% less nitrogen oxides (NO_x) and almost 100% less sulphur oxides (SO_x) than HFO. When the new IMO rules are applied, LNG will reach the requirements of these rules. Still, natural gas is a fossil fuel, and until all carbon can be captured, natural gas is only seen as a transition fuel on the way to a zero-carbon footprint. Biogas however, is seen as a carbon neutral fuel and can be used as a complement to LNG, which would improve the environmental impact significantly in the long term. (Fevre, 2018)

Table 1. Comparison of the emissions of marine fuels expressed in gram per gram of fuel. (Fevre, 2018)

Emissions (g/g of fuel)	Heavy fuel oil (HFO)	Marine diesel (MDO)	Liquified natural gas (LNG)
SO_x	0.049	0.003	Trace
CO_2	3.114	3.206	2.750
CH_4	Trace	Trace	0.051
NO_x	0.093	0.087	0.008
PM	0.007	0.001	Trace

The EU has also set targets to reduce the emissions within the union, progressively up to 2050. The first steps are the so-called 20-20-20 goals which are set for 2020. They aim to increase energy efficiency by 20%, reduce CO_2 emissions by 20% and have 20% of the energy be derived from renewables, compared to levels recorded in 1990. The emission reduction targets include housing, agriculture, waste and transport. (European Commission, 2018A)

The target for 2030 is to reduce greenhouse gas emissions by 40% below levels recorded in 1990, have a 27% share of renewable energy production and improve the energy efficiency by 27%. These targets will enable the EU to contribute to the Paris Agreement, and will result in a process that will aid in achieving a low-carbon economy with an energy system that will ensure affordable energy and environmental and health benefits. The 2050 long-term strategy aims to keep the temperature increase to far below 2 °C. (European Commission, 2018B)

1.2 Problem description

As mentioned earlier, in chapter 1.1, the LNG market is starting to expand. More ships are expected to use LNG as marine fuel and new regulations require shipowners to find other solutions to heavy fuel oil and marine diesel.

This growth can also be seen internally within Wärtsilä's Fuel Gas Supply Systems department (FGSS). Many projects are being received, and accordingly, more shipments are being sent out to manufacturers in China. In 2017, a total of 50 tons spread out over 320 boxes were shipped, and in 2018 approximately 83 tons and 600 boxes were shipped. According to internal estimations, the amount of shipments is expected to increase considerably in 2019, compared to numbers recorded in 2018. (Edsvik, 2019)

The aim of this master's thesis was to find out which freight method is most suitable as a shipping method for FGSS by taking environmental impact, costs and delivery times into account. This work was limited to the consolidated shipments that are sent to manufacturers from the warehouse in Vaasa and does not include the shipments that are received and consolidated in the warehouse in Vaasa. A comparison was made between the different freight methods, and calculations of the costs and total emissions were also made.

Rail freight between Finland and China was investigated more thoroughly, as a new route for container trains was opened in 2017 (Anteroinen, 2017). This freight method has also been mentioned as a good option in internal meetings at Wärtsilä, and therefore, rail freight will serve as a base for this master's thesis. Rail freight has never been used by the department, however, other departments within the company have had good experiences with this transportation method.

FGSS has its own environmental targets. One target is to reduce emissions from transportation by airplane, both regarding equipment and people. The amount of air freight must be defined, and a reduction target is to be set (Jansson, 2019). Even though the environmental impact is important however, the time and costs of the shipments also must be considered. The projects have tight time schedules and therefore, delays cannot occur, due to long shipment times.

Based on the theory presented and the calculations, a recommendation will be presented for how to lower the carbon footprint at FGSS and what the reduction target for 2019 should be.

1.3 Wärtsilä Fuel Gas Solution Systems

Wärtsilä’s Fuel Gas Solution Systems department is a part of Wärtsilä Gas Solutions and is specialized in developing, selling and delivering LNG storage and process systems to the marine business. In this era where emissions are more and more regulated and where the oil and fuel prices are volatile, using LNG as fuel is the perfect option. IMO’s new marine emission rules put even more pressure on ships to produce less emissions, which means the FGSS’s products are looking at a big growth in the future.

The two main products that FGSS is offering is the LNGPac (Figure 2) and the GVU (Figure 3). The LNGPac is a complete fuel gas handling system for LNG-fueled ships. It includes the LNG tank, bunkering station, control and monitoring system, aa well as process- related equipment such as compressors, evaporators, pumps, valves etc. This solution is made for type C pressure vessels and the LNG tank itself has a design pressure of 6-9 bar(g). To this day, over 100 LNGPacs have been delivered. The GVU is a module connected to the engine’s gas supply piping and each engine has its own GVU. The purpose of the GVU is to control the gas pressure to the engine according to the engine load.

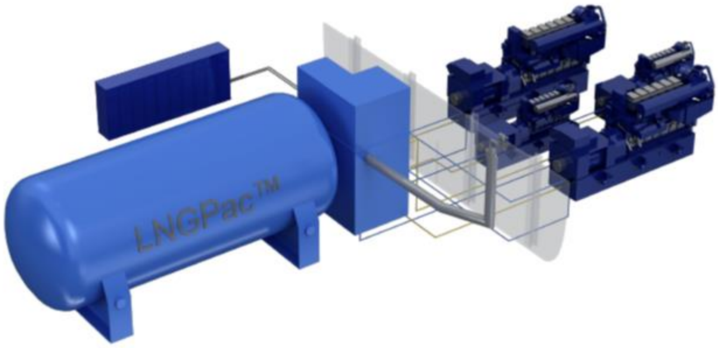

Figure 2. A simplified picture of the LNGPac (Wärtsilä, 2017)

Figure 3. Picture of the Gas Valve Unit (Wärtsilä, 2017)

1.4 FGSS shipment methods today

The project purchaser’s task is to order the components that are in the scope for the LNGpac. These components are then shipped from the suppliers to Wärtsilä’s warehouse in Vaasa, where the components are gathered into a consolidated shipment. The shipment is then sent to the tank and skid manufacturers, which often are located in China. Some components can be sent directly to the shipyards, which can be located anywhere in the world.

In principle, all shipments today are shipped by air freight. This is due to the projects at FGGS being sold with relatively short lead times, which means there is not enough time to send the components to the tank and skid manufacturers and by sea freight.

The only components that are sent by sea freight are large and heavy components that exceed measurements required for air freight. These components are not consolidated in Vaasa.

The average consolidated shipment weighs around 3,000 kg and contains approximately 20-30 packages in varying size. The components are packed into wooden, plywood or carton boxes. Packages that are shipped by sea freight require seaworthy packing, which wooden boxes are considered. Train freight has never been used at FGSS before, however, it is now being considered as a serious option to air freight, due to the cheaper cost and smaller carbon footprint.

2 THE NEW SILK ROAD TO CHINA

The Silk Road is an ancient trade route that ran from China to the West. China has lately been looking to create a new area of globalization by reconstructing the old Silk Road into a new Silk Road of the 21st century, and it is one of the largest infrastructure investments in history.

2.1 Background

In 2013, the President of China, Xi Jinping, announced an initiative to reopen the trade corridors to countries in the West. Most notably to Europe, the Middle East and central Asia, but also to Africa. The goal was to rebuild and create strategic propellers for hinterland development, accelerate the building of the belt and road to promote economic prosperity, strengthen exchange and cooperation between countries, and promote world peace and development. (ISDP, 2016)

ISDP (Institute for Security and Development Policy) mentions that this initiative is now called the Belt and Road Initiative. An action plan was released in 2015 by the Chinese National Development and Reform Commission, Ministry of Foreign Affairs, and Ministry of Commerce of the People's Republic of China, with State Council authorization.

China’s plan is to invest in infrastructure such as land routes (the Belt) and maritime routes (the Road) to improve trade relationships with Western countries. Railways, ports, pipelines, power grids and highways are to be upgraded in over 70 countries, and China is ready to lend up to $8 trillion to these countries. The new silk road will include 65% of the World’s population and 40% of the global gross domestic product as of 2017. (Lockhart, 2017)

Figure 4: A map showing the new belt and road routes between China and the Western countries (Lockhart, 2017)

2.2 Train freight from Finland to China

As a result of the Chinese initiative, a railroad was opened between Kouvola, Finland and Xian, China in November 2017. It became the first route for rail freight that connects the Nordic countries with China. (Päivinen, 2018)

The route from Kouvola to Xian is approximately 9,100 km long and passes through Russia and Kazakhstan before reaching the city of Xian in north-west China. The containers are reloaded from one train to another in the Kazakhstan City of Khorgos, since rail width differs between China and Kazakhstan. Finland, Russia and Kazakhstan have a similar rail width, with Finland having a track gauge of 1,520 mm, and Russia and Kazakhstan a track gauge of 1,524 mm. Containers can therefore be transported from Kouvola to Khorgos by the same train. The width of the Chinese railway is 1,435 mm and therefore, a change in trains is required. (Chartsbin, 2019)

The journey from Kouvola to Xian is expected to take 14 days, and in Xian there is also a possibility for fast connections to Shanghai that take two days. In 2019, a train departs from Kouvola to Xian approximately every other week. The operating train always has a minimum of 41 pieces of 40 ft containers, with the possibility to transport both full containers (FCL) and smaller volumes (LCL). The carrier on the route between Kouvola and Khorgos is KTZ Express (Kazakhstan railways), and International Port Multimodal Transport stands for rest of the route. (Pilli, 2019)

Figure 5. A map showing railway route between Kouvola and Xian (Suokas, 2018)

2.3 Kouvola Railroad Terminal

The Kouvola Cargo Handling terminal is the biggest logistics center in Northern Europe, and is the only Finnish rail road terminal. It has been part of the project of developing the Trans-European Transport Network (TEN-T) and has received EU funding. The terminal has 21,000 m^2 of warehouse space and room for six hectares worth of containers. Other warehouses, such as a paper warehouse, a pulp warehouse and glass logistics are also located in the area. The rail road terminal can receive trains that are up to 1,100 meters long, and has a possibility to load all wagon types. (Portaankorva, 2017)

The Kouvola Cargo Handling terminal also offers container stuffing, special cargo lashing and securing. There are railway connections between all the warehouses in the area, as well as multiple handling machines, such as forklifts, wheel loaders, overhead cranes, reach stackers and crane trucks to aid in storage and loading. Apart from rail freight the terminal also offers forwarding of road freight. (Portaankorva, 2017)

3 THEORY

3.1 Greenhouse gases and global warming

A greenhouse gas is a gas that traps heat in the atmosphere. More specifically, it absorbs and emits radiant energy within the thermal infrared range. The greenhouse gases are carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs). They have all been proven to cause the greenhouse effect which makes the earth habitable. Although, since the industrial revolution, the carbon dioxide concentration in the atmosphere has risen drastically, with CO_2 levels 100 ppm higher than 120 years ago (Figure 6). This rise has resulted in global warming, which raises the average temperature on Earth. (Lallalina, 2018)

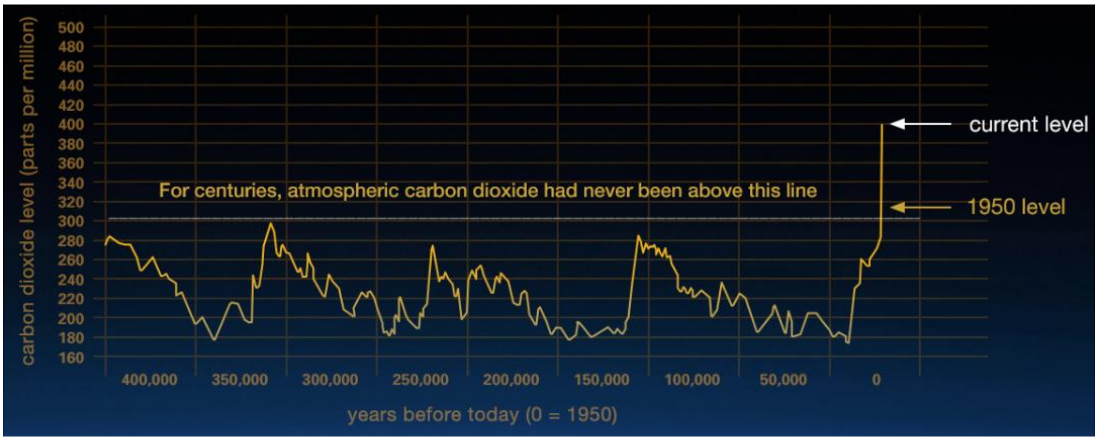

Figure 6. Graph of the comparison of carbon dioxide levels in the atmosphere, based on samples contained in the ice cores, which provides evidence that the CO2 level has increased since the Industrial Revolution. (Nasa, 2019B)

3.1.1 Effects of global warming

The increase in greenhouse gases in the atmosphere has increased the greenhouse effect, which as earlier mentioned has resulted in global warming. The greenhouse effect itself is a natural process that warms the surface of the Earth. The Earth is constantly exposed to enormous amounts of radiation from the sun, which strikes the atmosphere with both visible light, ultraviolet light, infrared light, along with other types of radiation. About 30% of radiation striking Earth is reflected into space by clouds, ice, snow, sand and other reflective surfaces. The other 70% is absorbed by land, atmosphere and oceans. Global warming causes a rapid increase in Earth's average surface temperature. As can be seen in Figure 7, the average temperature has drastically risen since the Industrial Revolution. (Nasa, 2010)

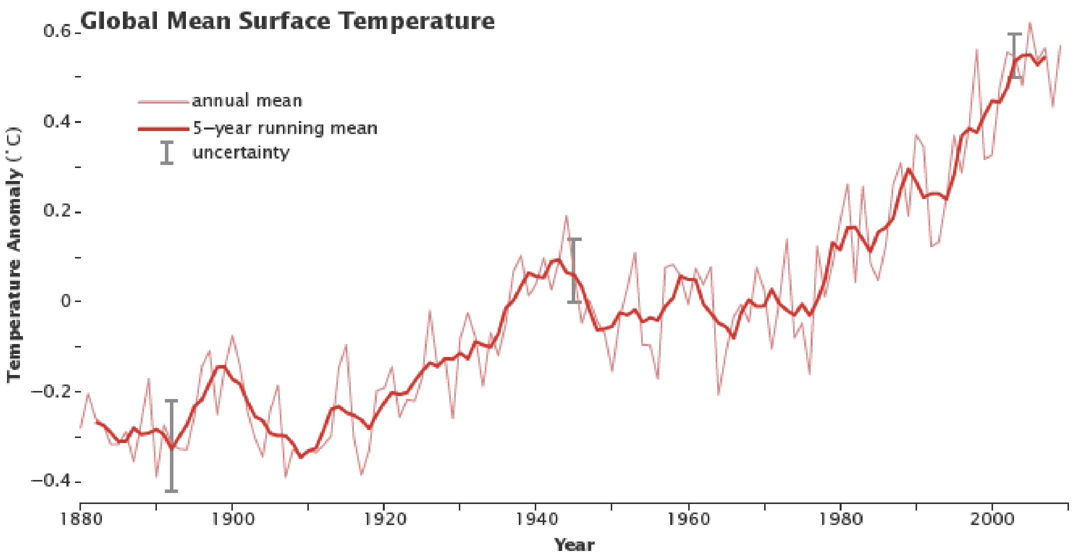

Figure 7. Global mean surface temperature between 1880-2010 (Nasa, 2010)

The greenhouse gases form a kind of blanket around the Earth. With the increase in greenhouse gases, the blanket becomes thicker, resulting in more heat getting trapped inside. In other words, it works like a greenhouse, hence the name, or like a car that is exposed to the sun in winter. The increase in temperature will result in snow and ice melting and turning into water, and therefore allowing more heat to be absorbed and trapped. Other effects caused by global warming are rising sea levels, an increase in ocean acidification, droughts, heat waves, hurricanes and other extreme weather events. (Nasa, 2019A)

Between 1880 and 2012, the average global temperature has risen by about 0.85 °C. The Intergovernmental Panel on Climate Change (IPCC) is striving to achieve a goal of limiting global warming to 1.5 °C over pre-industrial levels. Apart from the already mentioned effects that global warming will have, many species risk going extinct if the average global temperature exceeds 1.5°C (IPCC, 2018).

3.1.2 Carbon dioxide equivalent

The carbon dioxide equivalent (CO_2e) is a common unit for what global warming potential (GWP) the different greenhouse gases have. The equivalent can be used as a means to compare the GWP between different gases. Since CO_2 has the least global warming potential and is considered the most important gas of all greenhouse gases, it is used as the base of the comparison. As can be seen in Figure 8, methane has the CO_2e of 25. That means that 1 kg of methane in the air has the same GWP as 25 kg of carbon dioxide. This measurement is very useful since each greenhouse gas can be expressed as a number and can easily be compared to each other. (Brander, 2012)

Table 2. Comparison of global warming potential between the greenhouse gases (IPCC, 2007).

Greenhouse gas	Global Warming Potential (GWP)
Carbon dioxide (CO2)	1
Methane (CH4)	25
Nitrous oxide (N2O)	298
Hydrofluorocarbons (HFCs)	124 - 14,800
Perfluorocarbons (PFCs)	7,390 - 12,200
Sulphur hexafluoride (SF6)	22,800
Nitrogen trifluoride (NF3)3	17,200

3.2 Carbon cycle

Carbon is the fourth most abundant element in the Universe. It is essential for life on Earth and is the main component of biological compounds. Carbon is stored in rocks, the atmosphere, oceans, soil and in fossil fuels. The carbon cycle is the flow of carbon through the different reservoirs, e.g. from the atmosphere to the oceans, or from the soil to the atmosphere. Changes that put more carbon gases in the atmosphere result in a warmer climate on Earth. In the long term, the cycle maintains a balance that prevents all the world’s carbon to be stored in the atmosphere. This balance helps Earth’s temperature remain relatively stable. The cycle can furthermore be divided into the fast and the slow carbon cycle. (Riebeek, 2011)

3.2.1 The slow carbon cycle

In the slow carbon cycle, it takes between 100-200 million years for the carbon to change reservoirs between rocks, soil, ocean and atmosphere. In this cycle 10^{13} to 10^{14} grams (10–100 million metric tons) of carbon move each year. As a comparison, humans are emitting approximately 10^{15} grams of carbon each year. The movement of carbon from the atmosphere to the lithosphere (rocks) happens through rain. The carbon in the atmosphere combines with water and forms a weak acid that falls to the surface. The acid dissolves rocks, that release magnesium, sodium ions or potassium that are then transported to the oceans through rivers. The calcium ions merge with bicarbonate ions in the oceans to form calcium carbonate. This chemical compound is also made by e.g. shell-building organisms, plankton and corals. When these organisms die, they sink to the bottom of the seafloor, and over time these layers of shells and sediment bind together and turn into rock, storing the carbon in stone. (Riebeek, 2011)

The slow carbon cycle returns the carbon into the atmosphere through volcanoes. When they erupt, they vent the gas back into the atmosphere and spread rocks over the earth to start the process all over again. Between 130 and 380 million metric tons of carbon dioxide is emitted by volcanoes every year. It can be compared to the 100-300 times more, or 30 billion tons that humans emit every year through burning fossil fuels. (Smit et al, 2014)

The slow cycle also contains a moderately faster component, which is the ocean. Where the ocean's surface meets the air, carbon dioxide is dissolved into and ventilated out of the ocean. A steady exchange is in place between the oceans and the atmosphere. When carbon dioxide enters the water, it reacts with water molecules and releases hydrogen. This results in the ocean becoming more acidic. (Smit et al, 2014)

3.2.2 The fast carbon cycle

It takes around one human lifespan for carbon to move through the fast carbon cycle once. This cycle is largely seen as the movement of carbon through life forms on Earth. Between 10^{15} and 10^{17} grams (1,000 to 100,000 million metric tons) of carbon is moved through this cycle every year.

The main component of the fast carbon cycle is plants and phytoplankton. They take carbon dioxide from the atmosphere by absorbing it into their cells. They use the energy from the sun and water to turn carbon dioxide into sugar (CH_2O) and oxygen (O_2). The plants and phytoplankton use the sugar as energy to grow. The chemical reaction happens as following:

$$CO_2 + H_2O + \text{energy} = CH_2O + O_2 \qquad (1)$$

Plants can return carbon back into the atmosphere in different ways, however each way includes the same chemical reaction. As plants grow, they break down sugar in order to gain energy. Animals and people eat these plants or plankton, and break down the plant sugar as one way of receiving energy. Plants and plankton die and decay, and are eaten by bacteria at the end of the growing season, or alternatively, the plants can be consumed by fire. In each case, oxygen is combined with sugar to release water, carbon dioxide, and energy. (Riebeek, 2011)

$$CH_2O + O_2 = CO_2 + H_2O + \text{energy} \qquad (2)$$

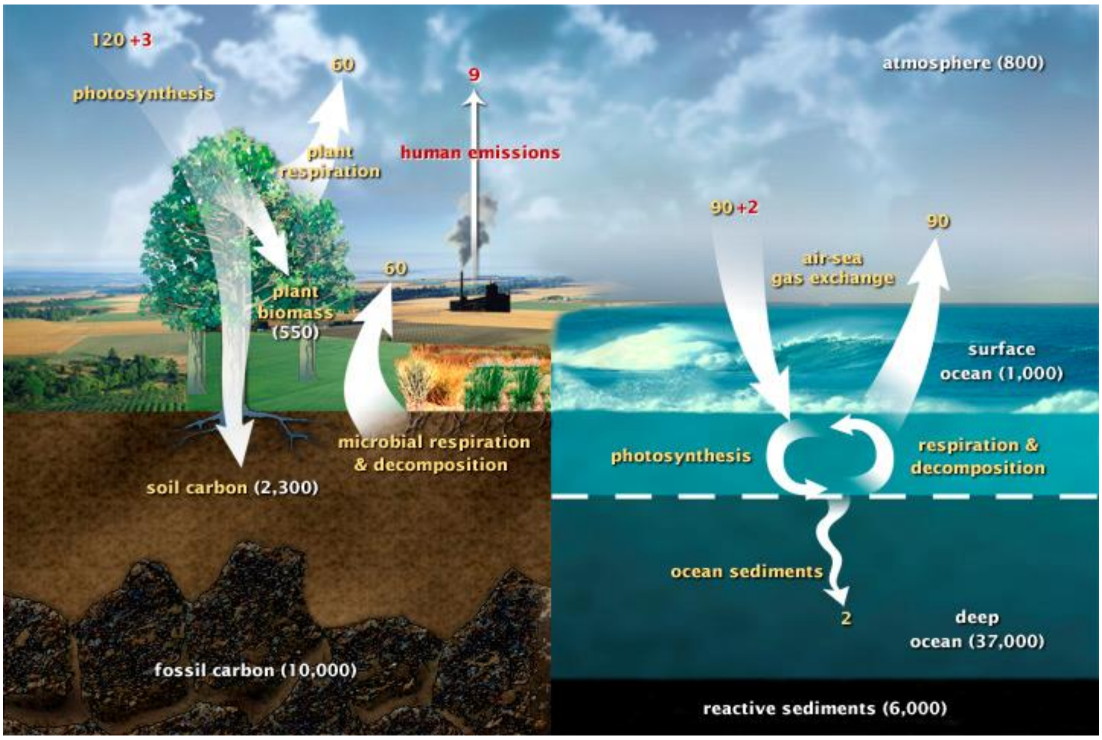

Figure 8. Picture showing the process of the fast carbon cycle. The movement of carbon between land, air and ocean. (Riebeek, 2011)

3.2.3 Effects of changes in the carbon cycle

When left uninterrupted, the slow and fast carbon cycle keep the carbon content in the atmosphere relatively steady. However, if anything causes a change in the amount of carbon in one of the different reservoirs, it will result in a ripple effect effecting the remaining reservoirs. At the moment, changes are happening in the carbon cycle because of humans, and more exactly due to the burning of fossil fuels and deforestation. All the extra carbon released needs to be stored somewhere. It is estimated that around 55% of the carbon released into the atmosphere has been absorbed by land and oceans, while 45% is left in the atmosphere. Over time, land and oceans will take up most of the carbon dioxide, however, approximately 20% will remain in the atmosphere. All this excess carbon dioxide in the atmosphere will lead to a warmer climate, and the excess amount in the oceans will result in increased water acidity, which will put marine life in danger. (Smit et al, 2014)

3.3 Sustainable development

Sustainable development is a concept in which development meets the needs of the present population, without compromising the possibility for future generations to meet their needs. This concept consists of three categories: environmental, economic and social sustainability. Sustainable development aims to address all environmental, economic, and socio-political problems, without compromising neither one or the other, and furthermore, without jeopardizing human capability and development. Only when the needs of these three categories are met, can society achieve a sustainable development. (Rogers et al, 2018)

Figure 9. Scheme of the sustainable development's different parts (Ashby, 2016)

Social sustainability affects people's life conditions in society, for example their health, security, education, justice and power. Human rights are also a foundation in this category. Economical sustainability implies that everybody should have the ability to accommodate their basic needs in relation to Earth's limited resources. Economic development should not proceed on the expense of the world's population or the environment. Environmental or ecological sustainability involves protecting the

Earth's ecosystem, developing smart climate solutions, along with reducing carbon dioxide and other greenhouse gas emissions. In conclusion, the development of our societies should not be at the expense of the environment, nor Earth's resources. (Ashby, 2016)

3.4 Sustainable transportation

Sustainable transportation implies transportation that is safe, has a low impact on the environment, as well as good energy efficiency. It makes use of renewable energy rather than the use of fossil fuels such as coal and petrol. The transportation sector is evolving, and favourable alternatives that reduce emissions have already been developed (Evans, 2011). Furthermore, hybrid and electric cars are steadily gaining popularity. As long as electricity produced for electric cars is derived from renewable sources, electric cars are an excellent option to old-fashioned petrol and diesel vehicles. Some vehicles have also started to run off biofuels. Biofuels are produced from biomass through biological processes, such as anaerobic digestion. Biofuels do create CO_2 emissions when combusted, although they are still considered a carbon neutral fuel since they come from renewable sources and are also part of the carbon cycle, as described in Chapter 3.2. Another fuel option is hydrogen gas, which can be produced from renewable energy sources and is a zero-emission fuel. When combusted, hydrogen (H_2) reacts with oxygen (O_2) and forms water vapor (H_2O). Even though this fuel is a favourable option when looking from an environmental standpoint, nitrogen gas is highly explosive. Also, the refuelling infrastructure is not built out vastly across the world. (Naturskyddsföreningen, 2014)

The importance of the need to adjust to more sustainable transportation methods can best be expressed in the total greenhouse gas emission numbers from the transportation sector. In 2016, the total emissions were 1,080 million tonnes CO_2-equivalent, which was 24% of EU's total CO_2 emissions. Even though the EU has set a target to reduce the overall environmental impacts in the mobility sector, emissions are still increasing. (EEA, 2018)

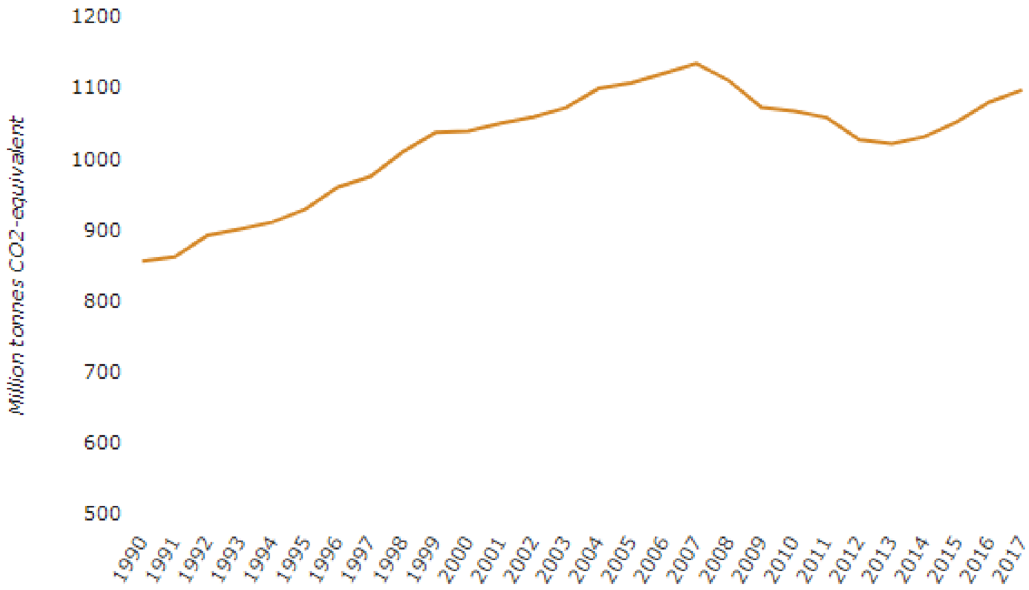

Figure 10. Greenhouse gas emissions from transport in the EU between 1990-2017 (European Environment Agency, 2018)

3.5 Environmental impact of transportation

The transportation sector greatly impacts the environment in relation to climate change, air quality, water quality, soil quality and noise pollution. Some of the results of these impacts are smog and acid rain. The transportation sector releases millions of tonnes of greenhouse gases each year, which has both a global and local impact. The environmental impacts are divided into three categories. (Rodrigue et al, 2017)

- ***Direct impacts*** – The immediate consequence of the environmental impact, where the cause and effect relationship are well understood.
- ***Indirect impacts*** – The secondary effect of transportation activities on environmental activities. They often have higher impacts on the environment than direct impacts, but the relationships involved are difficult to understand.
- ***Cumulative impacts*** – The synergetic effect of transportation activities. They take into account the varied effects of direct and indirect impacts of the ecosystem, which often are unpredictable.

Greenhouse gases have a big impact on global warming, as described in Chapter 3.1.1, and the transport industry is accountable for between 25-30% of all greenhouse gas emissions. Some gases are also causing a depletion of the stratospheric ozone layer, which screens the Earth's surface from ultraviolet radiation. It is N_2O in particular that is contributing to the damaging of the ozone layer. (Rodrigue et al, 2017)

The combustion of fossil fuels releases particulate matter such as ash and dust into the atmosphere. Other common particulate emissions include lead (Pb), nitrogen oxides (NO_x), carbon monoxide (CO), silicon tetrafluoride (SF_6), benzene and volatile components (BTX), as well as heavy metals such as zinc, copper, chrome and cadmium. These emissions are causing significant damage to human health and are associated with cancer, as well as cardiovascular, neurological and respiratory diseases. (SEPA, 2001)

According to the SEPA (Swedish Environmental Protection Agency), noise pollution has been proven to have negative effects on people's health. In cases of maximum sound levels or sudden changes in surrounding acoustics, several psychological systems in humans can be activated, which can result in an increase in heart rate, raised blood pressure, along with other reactions. Noise pollution can also affect sleep quality and cause sleep disturbances.

A further example of environmental effects from transportation is the acidification of water and land, which is caused by the emissions of nitrogen oxides (NO_x) and sulphur oxides (SO_x). These emissions contribute to nitrogen saturated soil and eutrophication of the seas. Furthermore, the acidification may also lead to negative changes in the conditions of life for animals, plants and micro-flora. (Sharma et al, 2012)

3.6 Freight transportation methods

Freight transportation is the process surrounding the transportation of commodities, merchandise goods and cargo. Freight methods can be split into three categories: land, air and water transportation. Land transportation can further be split into two subcategories: road and rail transport.

Road freight encompasses the transportation of goods with lorries. This method is often used when the distance between loading and unloading points are not overly far. For instance, if a product is to be transported within Finland or elsewhere in Europe, road freight would be viewed as the most suitable option. Rail freight includes transportation of goods with cargo trains. This method is often used when distances are slightly farther and there is no demand for flexibility. Sea and air freight are used when transportation distances are far. Sea freight is when ships are used for transportation, and air freight when using airplanes. These different freight methods will be compared in further detail in Chapter 3.8.

Beyond the four described freight methods there is also intermodular transportation, which is a combination of different freight methods. The process of intermodular transportation will be described in further detail in Chapter 3.7. (Ruchton, 2014)

3.7 Intermodular transportation

This transportation method refers to the transportation of goods using more than one freight method. There are mainly four functions that define the intermodular process; composition, connection (transfer), interchange and decomposition. (Rodrigue et al, 2017)

Composition is the process of assembling or consolidating freight at a terminal where some kind of intermodal interface can be offered between a local distribution system and an international or national distribution system. Essentially, cargo from different suppliers can be collected at a distribution centre and be forwarded to high capacity transport modes such as maritime or rail transportation. The most common transportation method for the composition process is truck transportation, since it offers flexibility and door to door shipments. Another service that is offered in this process is warehousing.

Connection, or transfer, involves a consolidated modal flow between two terminals which can take place over national or international distribution systems. These are high capacity transport modes, such as air, maritime or rail freight.

Interchange takes place at terminals to provide an efficient continuity to the transportation chain. These interchange terminals can be ports or transhipment hubs and can be both within national and international distribution systems.

Decomposition takes place when a freight has reached a terminal close to its destination. It then must be transferred to a local freight distribution centre. This step is often referred to as the last mile and is often seen as the most difficult step of the distribution chain.

Intermodular transportation is optimizing economic performance in the transportation chain by using different freight modes in a productive manner. This is achieved by using high capacity transportation modes for the biggest part of the trip and using flexible truck transportation to consolidate shipments and distribute cargo to its final destination. However, the important part of intermodular transportation is that the process is seen as a whole, rather than a series of legs marked by an individual operation. The use of intermodular transportation has also resulted in the development of management units of freight, which has resulted in international use and standardization of containers, swap bodies, pallets and semi-trailers. (Rodrigue et al, 2017)

3.8 Comparison of freight methods

All of the different freight methods mentioned have their own advantages and disadvantages, and are suitable for different kind of transportations depending on the weight, volume of the cargo and the transportation distance. A comparison of some central parameters for freight methods can be found in Table 3. A comparison of the emissions between the methods will be presented Chapter 3.9.2

The use of road freight is considered most suitable for short to medium distances. The amount of cargo a truck can load is limited; however, it is a the most flexible option of all the freight methods. There is the possibility of door-to-door transport and furthermore, the costs are relatively low.

Rail transport is most frequently used when distances are considered medium to long, and one of the advantages is the large loading capacity. The cost per tonne is also quite low, however flexibility is limited, and it may be difficult to find train connections when delivered from one country to another. (GWT, 2018)

Sea transport is the cheapest of the methods mentioned when comparing price per tonne (ICS,2014). This freight method is most suitable for long distances, and today's cargo ships have enormous loading capacities. The disadvantage, however, is the slow speed and the inflexibility. A shipment between Europe and Asia can take up to two months.

The use of air freight is most suitable for long distances and when cargo needs to be delivered quickly. However, loading capacity is limited, and taking the price in to consideration, this is the most expensive of the methods. The delivery is also restricted to journeys between airports. (White, 2015)

Table 3. Comparison of central parameters between freight methods (GWT, 2018)

	Road	Rail	Sea	Air
Relative speed	Moderate	Moderate	Slow	Very high
Reliability	Good	Good	Limited	Very good
Cost per tonne/km	Medium	Low/Medium	Low/Very low	High
Flexibility	High	Low	Low	Medium
Distances	Short to medium distances	Medium to long distances	Long distances	Long distances
Network /Infrastructure	Extensive network	Limited and fixed infrastructure	Restricted network	Limited network
Advantages	Relatively fast; No transhipment; Direct delivery; Flexible; Low costs	Economical; Large loading capacity; Range and speed	Economical; Large loading capacity; No restrictions on loading capacity	Fast; Reliable; Limited losses; Direct; Easy tracking and tracing
Disadvantages	Limited loading capacity; Affected by weather	Difficult finding freight cars; Delays; Transhipment; Inflexible; Tracking	Slow; Transhipment at ports; Inflexible	Expensive; Transhipment; Restricted loading capacity

3.9 Choosing freight method

When choosing freight method, a number of factors need to be taken into consideration in order to obtain the most suitable freight option. The selection process is divided into four categories or key stages that include covering operational factors, transportation mode characteristics, consignment factors and cost and service requirements. (Rushton 2014)

The operational factors are divided into external factors, customer characteristics and the physical nature of the product. The external factors that need to be investigated when shipping internationally are the basic infrastructure in the country, trade barriers, export control and licenses, law and taxation, culture and climate. All these can have a large impact on the different possibilities of freight options. Customer characteristics may also affect the choice of the transportation method. Service level requirements may affect delivery time, and delivery point constraints can affect whether it is even possible to unload the shipment or cause other access-related problems. Sometimes the customer might lack the right product knowledge, which could damage or harm the products. The physical nature of the product is one of the most determining factors when choosing the most suitable freight method. Here, volume and weight should be taken into consideration. Products that are considered too large and heavy may not suit air freight, for example. Also, sustainability or special characteristics should be taken in to consideration. The product may, for example, be fragile which can limit freight possibilities or have low sustainability, which might require fast transportation. (Rushton 2014)

Transportation mode characteristics have been described in Chapters 3.6-3.8, and as mentioned before, the freight methods all have their own advantages and disadvantages. The different areas that need to be taken into consideration when choosing freight method are the speed of the transportation, the total costs and the availability. Some orders might need to be delivered as fast and possible and the price may need to be compromised. In other cases however, the lowest price might be the ultimate goal. Some freight methods might not be available every day, like e.g. rail transport. This category also needs to consider delay or delivery problems, reliability, and the possibility of flexibility. (Rushton 2014)

Consignment factors normally relate to a specific characteristic of an order that may influence the selection of transportation mode. The factors include the following categories: distance, type of cargo, quantity, unit load, priority, and regular shipments. It is clear that all types of cargo, quantity and unit loads are not suitable for all freight methods, due to size limitations. The priority of the order weighs heavily, due to transportation time differing highly between methods. The regular shipment might affect the delivery time and flexibility of intermodular transportation. If, for example, a truck transport fails to deliver on time to a cargo train that is dispatched once a week, it causes serious delays in the transportation time. (Rushton 2014)

Cost and service requirements are a big part of the final selection of freight method. The choice is seen as the logistics trade-off between cost and service. This is something that needs to be considered in relation to the operational factors, transport mode characteristics and consignment factors. In theory, the size of the load and the distance traveled dictate the mode choice based on relative costs. In figure 14, the most suitable freight method can be found depending on size of load and delivery distance. (Rushton 2014)

Table 4. Modal choice matrix. Which delivery methods that are suitable for different distances and loads (Rushton 2014)

Size of load/ Delivery distance	Short	Medium	Long	Very long
100 tonnes	Road	Road/Rail	Rail/Sea	Rail/Sea
20 tonnes	Road	Road	Road/Rail	Rail/Sea
Pallet	Road	Road	Road/Rail	Air/Sea
Parcel	Road	Road/Air	Road/Air	Air

Apart from the mentioned categories used when deciding freight method, the aspects of international trade also need to be acknowledged. Trade agreements and economic unions can either enable or restrain trades between countries. Taxation, payment types and documentation can all have different rules in different countries and have to be studied before engaging in trade and logistics.

3.9.1 Comparison of transportation time

The transit time depends on which freight method that is used, and the destination of the transport. In case of intermodular transport, when different freight methods are used, there might be some delay in between changes of transportation method. The cargo may need to be transferred several times before reaching its destination. According to Freight Hub (2018), the typical transit times between Europe and Asia is 1 to 10 days for flight, 14 to 19 days by train and 23 to 43 days by boat. (Freight Hub, 2018)

3.9.2 Comparison of CO_2 emissions

Different freight methods use different vehicles for the transportation, which will result in differences in the total emissions between the methods. The total amount of CO_2 emissions for transportation are expressed in tonnes. The freight method's emissions are expressed as grams CO_2 per tonne-kilometre, where the CO_2 stands for the total mass of emissions, and where tonne per kilometre is the total transport work. From this value the total amount of CO_2 emissions can be calculated.

$$\text{CO2 efficiency} = \frac{\text{CO2}}{\text{tonne} * \text{kilometre}} \qquad (3)$$

As can be seen in Figure 13, the difference between the emissions, expressed in gram CO_2 emissions per tonne-kilometre, can be quite significant between methods. Air freight is by far the biggest source of CO_2 emissions, with 435 grams per tonne-km. Transport with a very large container vessel lays on 3 grams per tonne-km, whereas road freight lays on 80 gram per tonne-km (ICS, 2009). The CO_2 emissions can be calculated with Equation (4).

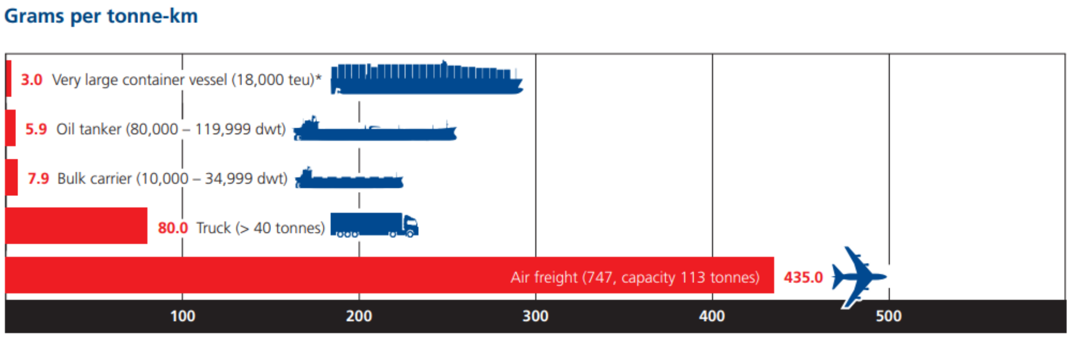

Figure 11. Comparison of typical CO2 emissions between modes of transport. Expressed in gram CO2 per tonne-kilometre (ICS, 2014).

The difference in emissions for rail freight can vary widely since some trains are hauled by diesel locomotives and others by electric ones. The power source of the electricity can also vary widely, and when transporting internationally, different countries might have different locomotives and power sources. This makes it difficult to estimate a number. For rail transport, an average CO_2-emission factor has been calculated by the European Chemical Transport Association (ECTA), and the result was 22 grams CO_2 per tonne-km. This number includes the average split between diesel and electric haulage, the average carbon intensity of the electrical power source, as well as the average energy efficiency of the locomotive. In Table 5, different emission factors by different organisations are shown and the table illustrates how much the values can differ. (ECTA, 2011)

Table 5. Rail freight emission factors published by different organizations. The emission factors are expressed as gram CO_2 per tonne-km (McKinnon, 2011)

Organisation	All rail freight	Diesel-hauled	Electric-hauled
ADEME	7.3	55	1.8
NTM	15	21	14
AEA Technology	20		
DEFRA	21		
INFRAS	22.7	38	19
TRENDS	23		
Tremove	26.3		
IFEU		35	18
McKinnon/EWS		18.8	

The total amount of CO_2 emission in tonnes for each freight method can be calculated from with Equation (4).

$$CO2\ emissions = \frac{tonnes * km * g\ CO2\ per\ tonne\ km}{1\ 000\ 000} \qquad (4)$$

Tonnes stands for the total transported cargo, km for the total distance of the transport. (ECTA, 2011)

3.9.3 GHG emission calculations challenges

The applied methods for calculating GHG emissions might differ and the evaluation of the result can be difficult, hence the results given can at times be doubtful. For example, biofuels are often seen as not producing any greenhouse gas emissions, which is an incorrect assumption. To produce biofuel, plants must be grown, harvested and transported, which uses energy, which creates emissions. To obtain exact results of the GHG emissions is very difficult, mainly since the fuels and vehicles used differ, but also because it could be problematic to make the right assumptions and take the whole logistics chain into consideration. Airplanes transport both people and cargo, hence why it can be difficult to allocate the calculated emissions and obtain a consistent methodology. Transport methods that are driven by electricity, can acquire the electricity from different sources. Also, the transportation of fuel to the power plants may be neglected. In practice, calculated values may only show part of reality. (CLECAT, 2012)

3.10 Intermodal containers

An intermodal container is a standardized shipping container. The container is designed and built for intermodular transport, which means that it can be used for different types of transportation methods, such as rail, road and maritime transport. They are primarily used in transport, and to store materials and products. Furthermore, intermodal containers are easy to handle, store and stack on top of each other. (Murphy, 2015)

Figure 12. Picture of a typical 40 ft container that is used for transportation. (PNG Logistics, 2015)

The container sizes are defined in the ISO standards. The most common sizes are 40 ft and 20 ft long containers. The most common heights are 8 feet and 6 inches and 9 feet and 6 inches, where the latter is known as a High Cube. A 20 ft container fits 11 euro-pallets and a 40 ft container 25 pallets. The difference occurs due to the containers having foot and inches as standard measurements, whereas in Europe centimetres are used as the standard measurement. (World shipping council, 2019)

Table 6. Container inner dimensions, volume and weights (World shipping council, 2019).

	unit	20 ft	40 ft	40 ft high cube
Length	m	5.89	12.01	12.01
Width	m	2.33	2.33	2.33
Height	m	2.38	2.28	2.69
Max gross weight	t	24.00	30.48	30.48
Max loading weight	t	21.60	26.50	26.50
Volume	m^3	32.66	63.80	75.28

4 MATERIAL AND METHODS

In this chapter the practical proceeding of this thesis will be presented. This in terms of calculations and suitable freight options.

4.1 Emission calculations

In order to calculate the total emissions for a certain transport method from Vaasa, Finland to Zhangjiagang, China, the total travelled distance must first be stated. For every freight method, the cargo first needs to be transported by lorry to a port, airport or railway station, and in the receiving country also from a port, airport or railway station, to the delivery address. These distances need to be stated, which can be seen in Table 7, and also be included in the emission calculations.

Table 7. Total transport distance for each freight method. The road freight distance to and from ports or airports are also included. The distances are based on own estimations using Google maps and flight distance calculator

Total distance (km)	Road Freight	Main Freight	Road Freight	Sea Freight
Sea Freight	423	26084	1063	
Rail Freight (Kouvola)	439	9100	1279	
Rail Freight (Hamburg)	1720	9688	831	120
Air Freight	432	7400	131	

The emission values were taken from the theory part of this thesis, Chapter 3.9.2. Each step of the total freight distance was calculated with the formula below.

$$CO2\ emissions = \frac{tonnes * km * g\ CO2\ per\ tonne\ km}{1\ 000\ 000} \qquad (4)$$

The total emissions were calculated in Excel for a shipment load of 2,156 kg and 5,000 kg. The load of 2,156 kg was chosen because it was a real case of a shipment that needed to be transported from Finland to China (see appendix 1). The 5,000 kg load was chosen as it at FGSS corresponds to a larger shipment. Both shipment loads are

LCL. The total emissions for transportations done during 2018 for FGSS were also calculated by using Formula 4. From that result, the total emissions reduced could be determined if using rail freight or sea freight instead of air freight.

4.2 Cost calculations

The cost calculations were made using the quotations stated in Appendix 2 as a base. Each offer stated the cost and delivery time for every individual freight method. From this, the costs were calculated per shipment, per 10 shipments and per 20 shipments with the same weight. Based on this, the possible savings were calculated, in the case that all shipments would change from air freight to either sea or rail. Road freight was left out of these cost calculations because it is not a valid option for transportation from Finland to China.

Table 8. The costs for a shipment of 2,156 kg, based on offers in Appendix 2.

Costs (€)	Per shipment
Sea Freight	€ 1,699.77
Rail Freight (from Kouvola)	€ 2,210.00
Rail Freight (from Hamburg)	€ 2,340.00
Air Freight	€ 2,861.00

The quotations were sent out at the end of March 2019 by the company's export coordinator. In accordance to his prior experience, the cheapest companies for each freight method were asked to send an offer for a shipment load of 2,156 kg including 29 boxes.

4.3 Selection of freight method

One proper way to decide which freight method that is the most suitable for FGSS, is to utilise a decision matrix (see Table 9). In the matrix a couple of different criteria are listed, as well as the importance of each criteria. To come to a conclusion, every alternative is walked through and given a valuation between one and five, where five is the highest score. The weight of the criterium and how well a freight method meets the criterium, together create a score. In the end, the total score for each criterium is summed up to a total score.

In the selection of suitable freight methods, the criteria that were weighed in were delivery time, costs per tonne kilometre, flexibility, loading capacity, regularity in shipments and emissions. The advantage of using a decision matrix is the ability to obtain a visual result of which methods are most suitable.

Table 9. Decision matrix. The total score shows which freight method is most suitable. The higher the score, the better the option.

Attributes -->	Delivery time	Cost per/tonne km	Flexibility	Loading capacity	Regularity in shipments	Emissions	TOTAL
Weight -->							SCORE
Air							
Rail							
Road							
Sea							

The weights of the attributes were discussed and chosen by the purchasing team. It is the purchasing team that arrange the transportations and that are responsible for shipments being delivered on time. The weight of the emission attribute was chosen according to feedback from the management team.

From the quotations in Appendix 2, the delivery times for each method were stated. For rail freight two offers were received, freight from Kouvola and from Hamburg. This was one central parameter in the decision matrix.

Table 10. Comparison of delivery time between freight methods, from Finland to China. These were the given data when making the decision matrix.

	Delivery time (days)
Sea freight	51
Rail freight (via Kouvola)	28
Rail freight (via Hamburg)	16-18
Air freight	5

5 RESULTS

5.1 CO_2-emission calculations

The emission calculations were made for three main freight methods; road, rail and air. Road freight was excluded as a main freight method from this study, due to the long transport distance from Finland to China. However, road freight was included in the transportation to and from ports, airports and rail stations.

The results below show the total emissions for a shipment of 2,156 kg and 5,000 kg, if they were to be shipped using different methods. The results clearly indicate that air freight has the biggest carbon footprint, with 7.07 tonnes and 16.32 tonnes CO_2 emissions. Sea freight has 93.9% less CO_2 emissions, and rail freight 89.6-87.2% less, when compared to air freight.

Table 11. Calculated total CO_2 emissions for three main freight options between Vaasa in Finland and Xian in China. For rail freight two options were considered, one via Kouvola and the other via Hamburg. The emissions were calculated for a freight weight of 2,156 kg.

Main Freight Method	Road Freight	Main Freight	Road Freight	Total
	CO_2 emissions, t			
Sea Freight	0.07	0.17	0.18	0.43
Rail Freight (via Kouvola)	0.08	0.43	0.22	0.73
Rail Freight (via Hamburg)	0.03	0.46	0.14	0.90
Air Freight	0.07	6.94	0.02	7.04

Table 12. Calculated total CO_2 emissions for three main freight options between Vaasa in Finland and Xian in China. For rail freight two options were considered, one via Kouvola and the other via Hamburg. The emissions were calculated for a freight weight of 2,156 kg and 5,000 kg.

Main Freight Method	Road Freight	Main Freight	Road Freight	Total
	CO_2 emissions, t			
Sea Freight	0.17	0.39	0.43	0.99
Rail Freight (via Kouvola)	0.18	1.00	0.51	1.69
Rail Freight (via Hamburg)	0.69	1.07	0.33	2.09
Air Freight	0.17	16.10	0.05	16.32

The calculations in Table 13 show the total emissions of all transported cargo from FGSS to China in 2018, which was a total of 83,786 kg. The total of 273.24 tonnes CO_2 is significantly higher than if the shipment had been sent by rail or sea freight. CO_2 emissions could be reduced by 245.13 tonnes if rail freight from Kouvola would have been used, a 238.43 tonne reduction by rail freight from Hamburg and 256.90 tonnes by sea freight.

Table 13. Calculations of the total emissions by air freight within FGSS 2018. The theoretical emissions for sea and rail freight have been compared with air freight emissions, and from this the theoretical emissions reduced have been calculated.

Total CO_2 Emissions FGSS (t)	Road Freight	Main Freight	Road Freight	Total Emissions (t)
Air Freight	2.84	269.71	0.88	273.42
Total if Rail Freight (Kouvola)	2.94	16.77	8.57	28.29
Total if Rail Freight (Hamburg)	11.53	17.86	5.57	34.99
Total if Sea Freight	2.84	6.56	7.13	16.52
Emissions reduced with rail freight (Kouvola)				**245.13**
Emissions reduced with rail freight (Hamburg)				**238.43**
Emissions reduced with sea freight				**256.90**

5.2 Cost calculations

The cost calculations have been made based on the price received from the offers for the different freight methods (see Appendix 2). The quotations clearly state that air freight is the most expensive method and sea freight the cheapest one. Therefore, some savings would be made in the possible change in transportation method from air freight to either sea or rail freight.

Table 14. Comparison costs for different freight methods between Finland and China. The prices include the main freight method and road freight to and from ports, railway stations and airports. The table includes calculations of the possible savings that could be received if changing freight method from air freight.

Costs (€)	Per shipment	10 shipments	20 shipments
Sea Freight	€ 1 699.77	€ 16 997.70	€ 33 995.40
Rail Freight (from Kouvola)	€ 2 210.00	€ 22 100.00	€ 44 200.00
Rail Freight (from Hamburg)	€ 2 340.00	€ 23 400.00	€ 46 800.00
Air Freight	€ 2 861.00	€ 28 610.00	€ 57 220.00
Savings with Rail Freight (K)	**€ 651.00**	**€ 6 510.00**	**€ 13 020.00**
Savings with Rail Freight (H)	**€ 521.00**	**€ 5 210.00**	**€ 10 420.00**
Savings with Sea Freight	**€ 1 161.23**	**€ 11 612.30**	**€ 23 224.60**

5.3 Selection of freight method

Based on the available theory and from earlier experiences from former shipments in other projects, it was concluded that air, sea, and rail freight all are valid options as freight methods. The decision matrix was created to aid in getting a visual result of which freight method is the most suitable, by weighing in the different criteria, as described in Chapter 4.3.

The result from the decision matrix in Table 15, shows that air freight is the most suitable freight method for FGSS, with a total score of 72. Rail freight from Hamburg comes in second, with a score of 70. Rail freight from Kouvola reached a score of 66 with sea freight closely following with a score of 65. Road freight is not considered as a freight option to China by the department, but it was included in the decision matrix to get an overview of all the freight methods. Road freight received a score of 63 which is the least of all methods.

Table 15. Decision matrix. The total score shows which freight method is most suitable. The higher the score, the better the option.

Attributes -->	Delivery time	Cost per/tonne km	Flexibility	Loading capacity	Regularity in shipments	Emissions	TOTAL
Weight -->	5	2	3	3	4	4	SCORE
Air	5	1	4	3	5	1	**72**
Rail (Kouvola)	3	3	2	5	2	4	**66**
Rail (Hamburg)	3	3	2	5	3	4	**70**
Road	1	3	4	4	5	2	**63**
Sea	1	5	1	5	3	5	**65**

6 DISCUSSION

6.1 Freight Method

As a result of the thesis the most suitable freight method for Wärtsilä FGSS has been stated, by taking delivery time, costs and CO_2 emissions into consideration. In order to come to a conclusion, a decision matrix was created. As has been described in the previous chapter and theory chapter, air freight is still the most suitable freight option for FGSS when transporting cargo from Finland to China; this, even though air freight has the highest costs and emissions. This is mostly due to the great scores air freight received in the decision matrix, from the short delivery time, flexibility and regularity in shipments. However, rail freight from Hamburg came in close to air freight when comparing scores. Rail freight from Kouvola, and sea freight are also excellent options when there is enough time to send shipments with these freight methods. The difference between rail freight from Kouvola and from Hamburg was mainly in the area of regularity of shipment times, as trains from Kouvola dispatch once every second week, and trains from Hamburg a couple of times a week. Therefore, the conclusion can be drawn that rail freight from Hamburg is the better option of the two.

The cost calculations show that money can be saved if the freight method was changed from air freight to a different freight method. With an increase in the demand for LNG fuel gas systems from the market, and with more future shipments that are to be delivered by FGSS, a significant sum can be saved.

Road freight was never considered as a transportation option from Finland to China, however it was still included in the decision matrix to give a comparison between all freight methods.

6.2 Reduction of the carbon footprint

Another aim of this thesis was to calculate FGSS's total emissions from air freight for 2018, and to give a recommendation on how to reduce the emissions from transportations. The emission calculations clearly show that air freight is the most pollutive freight method out of all the compared freight methods, and it also happens to be the freight method mainly used at FGSS.

It was easy to conclude that the freight method needs to be changed from air freight in order to reduce the carbon footprint. Even if a couple of shipments per year were to be changed to rail freight instead, the emissions would decrease significantly.

FGSS should aim to reduce emissions from transportation by 20% during 2019. This target is equal to sending 18,300 kg as rail freight instead of air freight. Sending 8,300 kg as rail freight instead, would result in a 10% decrease in emissions. Even though the projects at FGSS usually have very tight time schedules, this should be possible to achieve with good project planning.

It is important to mention that the emission factor for rail freight, expressed in grams CO_2 per tonne-kilometre, is unsure. The theory chapter acknowledges that different organizations have come out with different emission factors for rail freight, and these vary greatly. According to ECTA, 22 grams CO_2 per tonne-km include the average split between diesel and electric haulage, the average carbon intensity of the electrical power source and the average energy efficiency of the locomotive. This is also the number that has been used for the calculations, and when compared to Figure 11, also lies in between the organization’s different stated numbers.

As FGSS is supplying environmentally friendly products, it is great to see that they also want to lead by example and reduce their own emissions. The department has gained knowledge of the environmental impacts of the transportation and how these can be reduced.

7 CONCLUSIONS AND RECOMMENDATIONS

The different freight methods have been compared with each other and emission and cost calculations have been made. Based on the results, the most suitable freight method has been recommended along with a suggested emission reduction target. The internal knowledge of the environmental impacts of transportation, together with a clearer picture of the different freight method's emissions, have been achieved.

The next step will be to try sending a shipment as rail freight for a project and see if it is a reliable freight option that can be used more frequently in the future.

Further research could include investigating the amount of emissions that are released when Wärtsilä orders and transports components to the warehouse in Vaasa. Many of Wärtsilä's suppliers are located in Europe, and some components are also shipped from Asia. It would be interesting to investigate also this side of the supply chain.

Another aspect that could be further analysed is whether it would be practical to have the consolidation point of components somewhere in central Europe instead of in Vaasa. As mentioned earlier, many of Wärtsilä's suppliers are located in Europe, which means a more central consolidation point could reduce both transportation costs and emissions. One suggestion for a consolidation point could be in Hamburg, which is close to a rail-freight logistics hub, or Italy from where sea freight has a considerably shorter delivery time to China than from Finland.

The planning of projects and project execution could further be developed within FGSS. It would be desirable to be able to align the engineering and purchasing process better. A smoother execution of projects would help meet delivery times better and ensure that a more environmentally friendly freight method could be used instead of air freight. If rail freight were to be used more often for example, and logistics companies were to realise the growing demand, trains might depart more often, which would raise the score of rail freight in the decision matrix.

SWEDISH SUMMARY

Minskning av koldioxidavtrycket vid Wärtsilä Fuel Gas Supply Systems – En logistikanalys relaterad till den nya järnvägsrutten till Kina

Introduktion

Flytande naturgas har länge setts som framtidens marina bränsle, men när exakt den framtiden kommer har varit svår att förutspå. Tillväxten har varit långsammare än väntat och DNV GL (Det Norske Veritas och Germanischer Lloyd) har sänkt sin uppskattning för år 2020 från 1000 skepp drivna med flytande naturgas till mellan 400 och 600 skepp. Även om förväntningarna har sjunkit så har marknaden börjat ta vid. En stor orsak bakom tillväxten är nya internationella utsläppsregler, men även ett fluktuerande oljepris har fått skeppsägarna att se sig om efter bättre bränslealternativ. Investeringar har gjorts inom bunkringsinfrastrukturen, och för tillfället finns det 60 bunkringsstationer i världen med 28 till på kommande.

Den marina transporten står för ungefär 2,5 % av världens utsläpp av växthusgaser. Ungefär 1000 miljoner ton koldioxid släpps ut årligen. År 2020 kommer International Maritime Organization (IMO) att införa regler som förbjuder användningen av skepp som har ett större svavelinnehåll än 0,5 %. År 2018 beslöt samma organisation att implementera en strategi där överenskommelsen är att sänka växthusgasutsläppen med 50 % till 2050.

Naturgas har stora miljöfördelar jämfört med tjockolja och marindiesel. Flytande naturgas har ett 25 % mindre koldioxidutsläpp, 90 % mindre kväveoxider och nästan 100 % mindre svaveloxider jämfört med marindiesel. När de nya IMO-reglerna tas i bruk kommer flytande naturgas att hållas inom tillåtna gränser. Dock är ju naturgas ett fossilt bränsle, och tills allt koldioxid kan tillvaratas från utsläppen kan naturgas endast ses som ett övergångsbränsle, på väg mot ett koldioxidneutralt avtryck. Biogas, som är ett koldioxidneutralt bränsle, kan omvandlas till flytande form vilket som gör att bränslet kan användas på likadant sätt som flytande naturgas. Användningen av biogas skulle förbättra miljöpåverkan avsevärt.

EU har satt som mål att minska på utsläppen progressivt fram till år 2050 med år 2020 som första delmål. Då väntas det så kallade 20-20-20-målet uppnås, som siktar på att förbättra energieffektiviteten med 20 %, minska koldioxidutsläppen med 20 % och på att 20 % av energin ska utvinnas från förnybara energikällor. Målet för år 2030 är att sänka utsläppen med 40 % jämfört med nivån år 1990, att ha 27 % bättre energieffektivitet och att 27 % av energin ska komma från förnybara energikällor. Det långsiktiga målet är att lyckas hålla temperaturförändringen under 2 °C.

Fuel gas supply systems (FGSS) försäljningsvolym ökar i takt med den stigande populariteten av skepp drivna med flytande naturgas, vilket resulterar i fler transporter. Målet med denna avhandling är att hitta den fraktmetod som är den mest lämpade när man tar i beaktande miljöpåverkan, kostnad och tid. Arbetet kommer att begränsas till konsoliderade transporter som skickas från lagret i Vasa till tillverkare i Kina. Tågfrakt mellan Finland och Kina kommer undersökas noggrannare.

I dagsläget beställs komponenterna för projekten till Wärtsiläs lager i Vasa. Där konsolideras paketen och skickas till tanktillverkare i Kina. Majoriteten av frakten sker med flygfrakt på grund av tidsbrist i projekten. En del tunga komponenter skickas med båt.

Sidenvägen till Kina

Kina beslutade år 2013 att göra investeringar upp till 8 miljarder euro på järnvägar, hamnar, kraftnät, rörledningar och motorvägar i över 70 länder i ett försök att öka den internationella handeln och samarbetet med västländerna. Längs med den nya Sidenvägens rutt finns en befolkning som motsvarar 65 % av världens population och en omsättning på 40 % av världens bruttonationalprodukt.

Som ett resultat av investeringarna öppnades en järnvägsrutt mellan Kouvola och Xian år 2017. Rutten är 9100 kilometer lång och går från Finland via Ryssland och Kazakstan vidare till Kina. Resan tar ungefär 14 dagar och från Xian finns möjligheten till snabba transporter till Shanghai. Godståget har ett minimum av 40 stycken 41 fots containrar och avgår en gång varannan vecka.

Teori

Hållbar utveckling är ett koncept som består av de tre underkategorierna miljömässig, ekonomisk och social hållbarhet. Man strävar efter helhetslösningar där lösningen inom en kategori inte påverkar negativt en annan. Utsläppen från transporter påverkar miljön och därför bör samhället sträva efter en hållbar utveckling med hållbara transporter.

Växthusgaser är gaser som fångar värme i atmosfären. Till dess räknas koldioxid (CO_2), vattenånga (H_2O), metan (CH_4), kväveoxid (N_2O), ozon (O_3), klorfluorkarboner (CFC) och freoner (HFC). Sedan den industriella revolutionen har växthusgasernas mängd i atmosfären ökat med 100 ppm vilket har resulterat i en global uppvärmning. Ökad mängd växthusgaser förstärker även växthuseffekten som i sig behövs för att liv ska vara möjligt på jorden, men vid en för hög mängd växthusgaser samlas mer värme och skapar en sorts tjock atmosfärisk filt runt jorden. Detta resulterar i att mindre värme släpps ut från jorden, vilket gör att isarna smälter, vattennivån höjs, haven försuras och naturkatastrofer ökar i styrka.

Koldioxidekvivalent (CO_2e) är ett mått som beskriver hur stor global uppvärmningspotential en växthusgas har. Koldioxid, som är den växthusgas med minst uppvärmningspotential, används som grund. Koldioxidekvivalenten kan användas som ett jämförelsetal mellan de olika växthusgaserna. Till exempel har ett kilogram metan samma uppvärmningspotential som 25 kilogram koldioxid.

Kolcykeln är det naturliga flödet av kol mellan olika källor, till exempel mellan atmosfären och haven. Kolcykeln är uppdelad i den långsamma och den snabba cykeln. I den långsamma cykeln tar det 100–200 miljoner för kolet att byta källa mellan sten, mark, vatten och atmosfär. I denna cykel frigörs 10^{13} till 10^{14} gram (10–100 miljoner ton). Kolet i atmosfären binds till vatten och formar en svag syra som faller till jordens yta. Denna syra löser upp stenar som frigör magnesium, kalcium, natriumjoner och kalium som transporteras till haven genom floder. I havet binds kalciumet till bikarbonat, vilket bildar kalciumkarbonat som i sin tur bildar sten tillsammans med döda organismer. Kolet återvänder till atmosfären igen via vulkanutbrott. Den snabba cykeln tar ungefär en människas livstid och mellan 10^{15} och 10^{17} gram (1,000 till 100,000 miljoner ton) byter källa. I denna cykel använder sig växter av koldioxid för att bilda socker och syre. Kolet binds alltså till växterna och återvänder till jorden i de fall när växterna dör och bryts ner av bakterier, när de brinner upp eller när de förbrukas av människor eller djur. Kolcykeln hålls relativt stabil om den inte påverkas av externa faktorer. En sådan faktor är till exempel när människor förbränner fossila bränslen i snabb takt, vilket resulterar i en ökad mängd kol i atmosfären.

Frakt är en process som innebär transport av varor eller laster. Fraktmetoderna kan indelas i land-, luft- och havsfrakt, där landfrakt vidare kan delas in i väg- och tågfrakt. Alla de olika fraktmetoderna har sina för- och nackdelar. Vägfrakt lämpar sig bäst när avstånden är relativt korta. Möjligheten till flexibla transporter är en fördel och priset per ton är relativt billigt jämfört med andra fraktmetoder. Dock är lastkapaciteten begränsad. Järnvägsfrakten lämpar sig bäst för längre transportsträckor. Kostnaderna per ton är förmånliga men flexibiliteten och utbudet är begränsat. Havsfrakt är den billigaste transportmetoden sett till pris per ton. Den lämpar sig bäst för långa transporter men nackdelen är att den är väldigt långsam. Flygfrakt är den dyraste av metoderna och lämpar sig för längre transporter och är även den snabbaste av de nämnda fraktmetoderna. Utöver de nämnda metoderna finns även en femte fraktmetod, den intermodulära transporten, där fler än en av de berörda fraktmetoderna används.

Den intermodulära transporten har fyra huvudfunktioner. Den första är komposition, är processen där gods samlas vid en terminal för att distribueras vidare med till exempel båt eller tåg. Den andra huvudfunktionen, förbindelse, innebär att godset förflyttas via två nationella eller internationella terminaler. Den tredje funktionen är utbytet, som effektiviserar kontinuiteten i transportkedjan och tar godset vidare till den terminal som är närmast slutdestinationen. Detta kan ske till exempel från hamnar eller flygplatser. Den sista processen är upplösningen och den sker när godset överförs till ett lokalt distributionscenter som transporterar godset till slutdestinationen.

När man väljer en fraktmetod bör en del faktorer tas i beaktande så som operativa faktorer, fraktmetodernas egenskaper, leveransfaktorer samt kostnads- och servicefaktorer.

Olika fordon för transport används beroende på vilken metod som tillämpas, vilket ger upphov till olika mängder utsläpp. Som jämförelse orsakar båtfrakten 3 gram koldioxid per tonkilometer, tågfrakt 22 gram koldioxid per tonkilometer, vägfrakt 80 gram koldioxid per tonkilometer och flygfrakt 435 gram koldioxid per tonkilometer.

När man transporterar gods är det vanligast att använda sig av en container. Intermodulära containrar är standardiserade containrar som kan användas för olika fraktsätt. Den vanligaste storleken är 40 fots containern som har en innerlängd på 12,01 meter, en innerbredd på 2,33 meter samt en innerhöjd på 2,38 meter. Maximal lastvikt är 26,5 ton.

Material och metoder

För att beräkna de totala koldioxidutsläppen för de olika fraktmetoderna från Vasa, Finland till Zhangjiagang, Kina, behövdes den totala transporterade distansen tas i beaktande. För varje fraktmetod behöver lasten transporteras till och från en hamn, flygplats eller järnvägsstation.

Kostnadskalkylen gjordes utgående från de mottagna offerterna. Varje offert innehåller leveranstid samt pris. Utifrån detta räknades kostnaderna ut för varje fraktmetod, för en leverans, 10 leveranser och 20 leveranser. Från de värdena kalkylerades de möjliga inbesparingarna som skulle uppnås ifall man helt frångick flygfrakt.

Olika logistikföretag kontaktades för offert för att få en bättre förståelse av priset och leveranstiden. Varje fraktmetod har sina för- och nackdelar. För att få en klar bild över vilken fraktmetod som är bäst lämpad skapades en beslutsmatrix. I matrixen listades alla kriterier samt vikten av varje kriterium. Varje kriterium gavs poäng mellan ett och fem där fem är det bästa värdet. Därifrån summerades den totala poängen som beskriver vilken fraktmetod som lämpar sig bäst. Kriterierna som togs i beaktande var leveranstid, kostnad per tonkilometer, flexibilitet, lastningskapacitet, regelbundenhet av transport samt utsläpp.

Resultat

En utsläppskalkyl för de olika fraktmetoderna gjordes. Vägfrakten är exkluderad som huvudfraktmetod på grund av att distansen mellan Finland och Kina är för lång. Vägfrakten inkluderades som fraktsätt från och till hamnar, flygplatser och järnvägsstationer. Resultatet visar utsläppen för en last på 2156 kilogram och 5000 kilogram, och demonstrerar tydligt att flygfrakten ger upphov till högst mängd utsläpp. Havsfrakt och tågfrakt har 93,9 % respektive 89,6 % lägre koldioxidutsläpp.

Fuel Gas Supply System (FGSS) transporterade 83 786 kilogram gods från Finland till Kina med flygfrakt år 2018. Den totala mängden koldioxidutsläpp var 273,24 ton, vilket är betydligt högre än om samma mängd hade transporterats med havs- eller tågfrakt. Vid användning av endast havs- eller tågfrakt skulle utsläppen ha minskat med 256,90 respektive 252,93 ton.

Kostnadskalkylen utgick från de priser som presenterades i offerterna. Anbuden visar tydligt att flygfrakt är den dyraste metoden och havsfrakt den billigaste. Därför kunde signifikanta besparingar erhållas vid byte från flygfrakt till annan fraktmetod.

Utgående från tillgänglig teori och tidigare projekttransporter kunde konstateras att havs-, tåg- och flygfrakt alla är lämpliga transportalternativ. Beslutsmatrixen skapades för att visualisera resultatet över vilken som är den mest lämpade fraktmetoden. Resultatet visar att flygfrakten fortfarande är det bästa alternativet med poängantalet 72. Tågfrakten kom på andra plats med en poäng på 66 och sjöfrakten med 65 poäng.

Diskussion

Ett av målen med detta arbete var att avgöra vilken som är den mest lämpade fraktmetoden i förhållande till kostnad, leveranstid och mängden koldioxidutsläpp. För detta skapades en beslutsmatrix. Som tidigare beskrivits är flygfrakt fortfarande det mest lämpliga alternativet vid frakt från Finland till Kina även om den metoden har högst kostnad och utsläpp. Detta beror på att flygfrakten fick bra betyg för dess korta leveranstid, flexibilitet samt regelbundenhet av transporter. Dock är tåg- och havsfrakt goda alternativ när det finns tid att använda dessa metoder. Det bör nämnas att vägfrakt aldrig var ett alternativ som fraktmetod mellan Finland och Kina, men togs ändå med i beslutsmatrisen för att få en jämförelse mellan alla fraktmetoder.

Kostnadskalkylen visar att det är ekonomiskt lönsamt att byta fraktmetod från flygfrakten. Om efterfrågan på marknaden ökar för bränslesystem för flytande naturgas och transporterna ökar så kan en signifikant summa pengar inbesparas.

Ett annat mål med detta arbete var att räkna ut de totala utsläppen för flygfrakt för år 2018 samt att ge rekommendationer för hur utsläppen kan reduceras. Som beräkningarna visar är flygfrakten den mest förorenande fraktmetoden. Därför var det entydigt att flygfrakten bör bytas ut mot andra transportmetoder för att minska på koldioxidavtrycket. Även om endast några transporter per år skickas med till exempel tågfrakt, kunde utsläppen minskas väsentligt.

Målet bör därför vara att minska på utsläppen med 20 % år 2019, vilket motsvaras av att sända 18 300 kilogram med tågfrakt istället för flygfrakt.

Det bör nämnas att utsläppsvärdet för tågfrakten, uttryckt i gram koldioxid per tonkilometer, är aningen osäkert. Olika organisationer har kommit ut med varierande värden. Enligt ECTA (European Chemical Transport Association) är 22 gram koldioxid per tonkilometer ett utsläppsmedeltal mellan diesel- och eltåg, samt eltågets energikälla. Det är också detta värde som har använts i beräkningarna.

Slutsats och rekommendationer

De olika fraktmetoderna har jämförts med varandra och utsläpps- och kostnadsberäkningar har utförts. Baserat på resultatet av beräkningarna har den bästa fraktmetoden rekommenderats. En rekommendation har även givits för hur utsläppen kan reduceras. Avdelningens interna kunskaper har stärkts gällande hur transporten av gods påverkar miljön samt de olika fraktmetodernas utsläpp. Nästa steg är att sända en transport från Finland till Kina med tågfrakt för att utreda om denna fraktmetod är pålitlig.

Som vidare forskning har föreslagits att analysera hur mycket utsläpp som uppstår när komponenter transporteras till lagret i Vasa. Många leverantörer är belägna ute i Europa, och en del komponenter kommer även från Asien. Det vore därför intressant att undersöka denna sida av logistikkedjan.

En annan aspekt som vidare kunde undersökas är om det vore vettigt att ha en konsolideringspunkt någonstans i Central- eller Sydeuropa istället för i Vasa. Många leverantörer finns ute i Europa, vilket betyder att en mer central konsolideringspunkt kunde minska på både fraktkostnaderna och utsläppen.

Även planeringen av projekten samt projektutförandet kunde vidare utvecklas inom avdelningen. Om projekten utfördes effektivare kunde leveranstiderna mötas bättre och man kunde säkerställa att det finns tid för mer miljövänliga fraktmetoder.

REFERENCES

Anteroinen, S. (2017). *Railforum 2017 – New rail connection to China launches in November.* Available at: https://www.kinno.fi/en/news/railforum-2017-new-rail-connection-china-launches-november [Accessed 22-01-2019]

Ashby, F. (2016). *Materials and sustainable development.* 1st ed. Butterworth-Heineman, Oxford, 312 p.

Brander, M. (2012). *Greenhouse Gases, CO_2, CO_2e, and Carbon: What do all these terms mean?,* Document, Ecometrica, 3 p.

Bruce-Lockhart, A. (2017). *China's $900 billion new silk Road – What you need to know,* Article, World Economic Forum, Available at: https://www.weforum.org/agenda/2017/06/china-new-silk-road-explainer [Accessed 23-02-2019]

Chartsbin (2019). *Railway track gauges by country.* Available at: http://chartsbin.com/view/38573 [Accessed 21-03-2019]

CLECAT (2012). *Calculating GHG emissions for freight forwarding and logistics services in accordance with EN 16258*, Guide, European Association for Forwarding, Transport, Logistics and Customs Services, 63 p.

Edsvik, C., Project purchaser, Wärtsilä FGSS, Internal communication January 2019

ECTA (2011). *Guidelines for measuring and managing CO_2 emissions from freight transport operations*, Document, European Communities Trade Mark Association, Issue 1, 18 p.

European commission (2018A). *2020 climate & energy package*. Available at: https://ec.europa.eu/clima/policies/strategies/2020_en#tab-0-0 [Accessed 04-03-2019]

European Commission (2018B). *2030 climate & energy framework*. Available at: https://ec.europa.eu/clima/policies/strategies/2030_en [Accessed 04-03-2019]

European Environment Agency (2018). *Transport greenhouse gas emissions*. Available at: https://www.eea.europa.eu/airs/2018/resource-efficiency-and-low-carbon-economy/transport-ghg-emissions [Accessed 20-03-2019]

Evans, M. (2011). *Sustainable transport*, Article, Earth Times. Available at: http://www.earthtimes.org/encyclopaedia/environmental-issues/sustainable-transport/ [Accessed 22-02-2019]

Fevre, C. (2018). *A review of demand prospects for LNG as a marine transport fuel*, Paper, Oxford Institute for Energy Studies, Oxford, 30 p.

Freight hub. (2018) *Modes of Transportation explained: Which type of cargo and freight transportation is the best?* Available at: https://freighthub.com/en/blog/modes-transportation-explained-best/ [Accessed 20-02-2019]

GWT (2018). *Sea vs Road vs Air freight – Which on is right for you*. Available at: https://gwtimpex.co.uk/sea-vs-road-vs-air-freight/ [Accessed 03-04-2019]

Hyytiäinen, V. (2019). *Zhangjiagang rahtikysely SP/02924 RAIL LCL*, quotation. 29.2.2019.

ICS (2014). *Shipping, world trade and he reduction of CO_2 emissions – United nations framework convention on climate change (UNFCCC)*, Document, ICS , 6 p.

IMO (2018). *Low carbon shipping and air pollution control*. Available at: http://www.imo.org/en/mediacentre/hottopics/ghg/pages/default.aspx [Accessed 15-01-2019]

IMO (2009). *Second IMO GHG study 2009*, Report, IMO, London, 219 p.

IPCC (2008). *IPCC Fourth Assessment Report: Climate Change 2007, Report, Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 976 p.

IPCC (2018). *Special report – Global warming of 1.5°C, report,* intergovernmental panel on climate change, IPCC, 32 p.

ISDP (2016). *The belt and road initiative*, publication, Institute of security and development publication, 7 p.

Jansson, M., general manager, Wärtsilä FGSS, internal email January 2019.

Lallanila, M. (2018). *What is the greenhouse effect?* Article, live science. Available at: https://www.livescience.com/37743-greenhouse-effect.html [Accessed 11-02-2019]

McKinnon, A. & Piecyk, M. (2011). *Measuring and Managing CO2 Emissions of European chemical transport*. Logistics research centre, Heriot-Watt university, Edinburgh, UK, 35 p.

Murphy, P., & Knemeyer, M. (2015). *Contemporary logistics*, 11th ed. Boston: Pearson cop. 317 p.

Nasa, (2010). *Global warming*. Available at: https://earthobservatory.nasa.gov/features/GlobalWarming/page2.php [Accessed 08-02-2019]

Nasa, (2019A). *How climate is changing*. Available at: https://climate.nasa.gov/effects/ [Accessed 08-02-2019]

Nasa, (2019B). *Climate change*: How do we know? Available at: https://climate.nasa.gov/evidence/ [Accessed 09-02-2019]

Naturskyddsföreningen (2014). *Biobränslen för en hållbar framtid – utmaningar för ett 100 % förnybart energisystem i Sverige*, Rapport, Naturskyddsföreningen (Swedish), 44 p.

Pilli, R. (2019). *Kouvola cargo handling - China block train*. Available at: https://cargohandling.fi/en/china/#1536845669867-eba21bc1-ae3d4cbf-11ea632c-1626 [Accessed 15-02-2019]

PNG Logistics. (2015). *New container weight rules*. Available at: http://pnglc.com/new-container-weight-rules/ [Accessed 20-03-2019]

Portaankorva, P. (2017). *Rail road terminal*., presentation, Kouvolan kaupunki, 5 p.

Päivinen, S. (2018). *Railgate Finland Kouvola - China express to launch weekly service*, Article, Business Finland. Available at: https://www.investinfinland.fi/-/railgate-finland-kouvola-china-express-to-launch-weekly-service [Accessed 2019-04-01]

Riebeek, H. (2011). *The carbon cycle*, Article, Nasa Earth Observatory. Available at: https://earthobservatory.nasa.gov/features/CarbonCycle/page1.php [Accessed 28-02-2019]

Rodrigue, J-P., Cintios, C. & Slack, B. (2017). *The geography of transport systems*, 3rd ed. Routledge, Taylor & Francis Group, London, 411 p.

Rogers P., Jalal, K. & Boyd, A. (2008). *An introduction to sustainable development*, 1st ed. Earthscan, London, 416 p.

Ruchton A., Croucher, P. & Baker, P. (2014). *The handbook of logistics & distribution management*, 5th ed. Kogan Page, London, 689 p.

SEPA (2001), *Environmental impact from different modes of transport – method of comparison*, Report, Swedish Environmental Protection Agency, 61 p.

Sharma, R.K. & Kumar, S. (2012*). Impact of transportation system on environment in developing countries*, Article, International journal of research review in engineering science and technology, volume 1, issue 2, 66 p.

Smit, B., Bourg, I., Oldenburg, C. & Reimer, J. (2014). *Introduction to carbon capture and sequestration*, 1st ed. Imperial College Press cop., London, 580 p.

Sollied, S-E. (2019). *Sulphur cap ahead – Time to take action*, Article, DNV-GL. Available at: https://www.dnvgl.com/article/sulphur-cap-ahead-time-to-take-action-94198 [Accessed 09-01-2019]

Suokas, J. (2018). *China-Finland cargo train link extends to Norway and Sweden*, Article, GB times. Available at: https://gbtimes.com/china-finland-cargo-train-link-extends-to-norway-and-sweden [Accessed 02-02-2019]

White, J. (2015). *Logistics operational guide*, Operational guide, Digital logistics capacity assessments.

Wold, M-C. (2017). *Uptake of LNG as a fuel for shipping*, Article, DNV-GL. Available at: https://www.dnvgl.com/article/uptake-of-lng-as-a-fuel-for-shipping-104195 [Accessed 08-01-2019]

World shipping council (2019). *Containers*. Available at: http://www.worldshipping.org/about-the-industry/containers [Accessed 02-03-2019]

Wärtsilä (2017). *Wärtsilä LNGPac™*, product leaflet, Wärtsilä, 4 p.

APPENDICES

Appendix 1

Case specification of the shipment

Case Specification

Ferus Smit 451	LNGPac loose to FCIT			
Shipment	631733		Wärtsilä Contact Person	
WBS	SP/02924		Shipment Status	Planned
FL	SP/02924.1.S.OG2		Planned Shipment Start	4.10.2019
Incoterms	DAP			

Total	Cases	Gross Weight (kg)	Net Weight (kg)	Vol (m³)
	29	2156,24	1741,8	6,898

Delivery	Handling Uni	Vendor	Picked Items Locat.	Purch. Doc.	Description	Gross Weight (kg)	Net Weight (kg)	Lenght (cm)	Width (cm)	Height (cm)	Vol (m³)	Locatio	Countr	Mat. No.
66143656	1000347830	93668		4503788788	GLOBE VALVE	250	220	120	80	100	0,960	RUNSOR	FI	PAAF245606
66143656	1000347829	93668		4503788788	GLOBE VALVE	391	360	120	80	100	0,960	RUNSOR	FI	PAAF305551
66152848	1000352395	88935		4504152785	RELIEF VALVE	242	162	128	73	118	1,103	RUNSOR	FI	PAAF207685
66154377	1000353186	211725		4504289719	PRESSURE TRANSMITTER	6,24	4,8	48	28	20	0,027	RUNSOR	FI	PAAF366670
66158759	1000355213	7267		4504309256	VALVE	4	3,6	50	25	30	0,038	RUNSOR	FI	PAAF560972
66159003	1000355232	4266		4504303750	CONNECTING CABLE	7	6	41	34	30	0,042	RUNSOR	FI	PAAF256459
66160803	1000356453	34961		4504309158	PRESSURE GAUGE VALVE	9	9	39	30	22	0,026	RUNSOR	FI	PAAF054083
66160803	1000356454	34961		4504309158	ADAPTER	10	10	39	30	22	0,026	RUNSOR	FI	PAAF054274
66162405	1000357021	30326		4503771316	MGE	222	175	80	80	80	0,512	RUNSOR	FI	
66162405	1000357029	30326		4503771316	MGE Ref evaporator	247	200	80	80	80	0,512	RUNSOR	FI	
66162405	1000357022	30326		4503771316	PBE Ref evaporator	262	215	80	80	80	0,512	RUNSOR	FI	
66162405	1000357023	30326		4503771316	PBE	227	180	80	80	80	0,512	RUNSOR	FI	
66163329	1000357423	211725		4504320095	PRESSURE TRANSMITTER	6	5	49	29	20	0,028	RUNSOR	FI	PAAF366670
66164563	1000358316	4266		4504320149	CONNECTING CABLE	25	24	58	38	49	0,108	RUNSOR	FI	PAAF256459
66164563	1000362598	4266		4504320149	LIMIT SWITCH	1	1	25	16	12	0,005	RUNSOR	FI	PAAF115445
66168779	1000360497	9193		4504328055	BALL VALVE	3	2	29	26	34	0,026	RUNSOR	FI	PAAF048124
66168929	1000360426	5930		4504303780	CONNECTION BOX	5	4	34	25	20	0,017	RUNSOR	FI	PAAF590076
66171042	1000361271	8787		4504289752	VALVE ASSEMBLY	1	1	29	20	10	0,006	RUNSOR	FI	PAAF280809
66171048	1000361272	34961		4504320054	PRESSURE GAUGE VALVE	4	3	39	30	15	0,018	RUNSOR	FI	PAAF054083
66171063	1000361273	34961		4504303714	PRESSURE GAUGE VALVE	26	6	50	41	49	0,100	RUNSOR	FI	PAAF054083
66171584	1000362006	34961		4504309139	TEMPERATURE SENSOR	3	2	39	30	22	0,026	RUNSOR	FI	PAAF570087
66171903	1000362023	211725		4504309149	TEMPERATURE SENSOR	75	55	77	99	66	0,503	RUNSOR	FI	PAAF315828
66172522	1000362048	34961		4504308840	PRESSURE GAUGE VALVE	2	1	30	20	15	0,009	RUNSOR	FI	PAAF606523
66173678	1000362593	3530		4504308975	BLEED SCREW	1	0,4	32	19	25	0,015	RUNSOR	FI	PAAF296138
66173713	1000362595	3957		4504320129	Emergency stop button	7	2	40	40	40	0,064	RUNSOR	FI	
66182143	1000367635	8787		4504308966	BUTTERFLY VALVE	12	10	60	40	23	0,055	RUNSOR	FI	PAAF606479
66186963	1000370196	5930		4504320146	LIGHTING FIXTURE	28	20	80	65	45	0,234	RUNSOR	FI	PAAF308608
66186963	1000370194	5930		4504320146	SWITCH	30	20	80	60	55	0,264	RUNSOR	FI	PAAF308618
66186963	1000370195	5930		4504320146	Field station I/O box	50	40	80	60	40	0,192	RUNSOR	FI	

Quotations for different freight methods

Sea freight quotation, part 1/2

DHL Global Forwarding

LCL-tarjous Wartsila Finland Oy

Tarjousnumero: HEL_6939

Voimassaoloaika: 01 huh. 2019 - 30 huh. 2019

Päiväys: 01 huh. 2019

Sopimus astuu voimaan ilmoitettuanne tarjouksen hyväksymisestä allekirjoittaneelle ja koskee kaikkia lähetyksiä, joiden toimeksianto annetaan hyväksymisen jälkeen. Hyväksymällä tämän tarjouksen sopimukseksi, valtuutatte DHL:n toimimaan tulliedustajananne. Toimeksiannon yhteydessä pyydämme ilmoittamaan tämän tarjouksen numeron.

Attn:	Teemu Lakka teemu.lakka@wartsila.com	Myyntikontakti:	Jari Kiukkonen jari.kiukkonen@dhl.com Tel. +358 40 5127671	Tarjouksen tekijä:	Jari Kiukkonen jari.kiukkonen@dhl.com Tel. +358 40 5127671

LÄHETYKSEN TIEDOT

Lähtösatama/-terminaali:	Helsinki (FIHEL), Finland	Saapumissatama/-terminaali:	Tianjin (CNTSN), China
Palvelu:	LCL GENERAL	Arvioitu kuljetusaika (päivinä):	51 päivä(ä) (CFS to CFS)
Lentoyhtiö / Varustamo:	DANMAR Lines		

Tarjouksen veloitukset

Vientikulut: Helsinki

Veloituksen nimi	Yksikkö	Painoluokka	Valuutta	Hinta
Vientihuolinta (OADM)	Per House Bill Of Lading		EUR	60.00
Vientiselvitys lisänimikkeet (OCAL)	Per Additional Line		EUR	6.00
Vientiselvitys (OCLE)	Per Entry		EUR	30.00
Danmar Lines B/L konossementti (ODBL)	Per Entry		EUR	31.00
Kotimaan polttoainelisä (OFSC)	Percentage On Pick Up		EUR	28.61
ISPS Turvatarkastusmaksu (OISP)	Per House Bill Of Lading		EUR	8.00
Nouto (OPUP)	Minimum (Per Shipment)		EUR	29.50
	Per Kilogram	<100	EUR	0.39
	Per Kilogram	>100	EUR	0.21
	Per Kilogram	>300	EUR	0.15
	Per Kilogram	>500	EUR	0.13
	Per Kilogram	>1000	EUR	0.07
	Per Kilogram	>2000	EUR	0.06
	Per Kilogram	>3000	EUR	0.05
	Per Kilogram	>4000	EUR	0.04
	Per Kilogram	>5000	EUR	0.04
Nouto (OPUP)	Minimum (Per Shipment)		EUR	72.00
	Per Weight Measurement		EUR	20.00
AMS/ACI-maksu (OSEC)	Per House Bill Of Lading		EUR	25.00
Terminaalikulut (OTHF)	Minimum (Per Shipment)		EUR	39.00
	Per Weight Measurement		EUR	22.00
Solas VGM (OVGA)	Per House Bill Of Lading		EUR	10.00
Tavaramaksu (OWHA)	Minimum (Per Shipment)		EUR	18.50
	Per Weight Measurement		EUR	3.14

Rahtikulut: Helsinki-Tianjin

Veloituksen nimi	Yksikkö	Painoluokka	Valuutta	Hinta
Rahti (FRT)	Minimum (Per Shipment)		USD	82.00
	Per Weight Measurement		USD	82.00
Low Sulfur lisä (MLSF)	Minimum (Per Shipment)		USD	3.00
	Per Weight Measurement		USD	3.00

Tuontikulut: Tianjin

Veloituksen nimi	Yksikkö	Painoluokka	Valuutta	Hinta
Tuontihuolinta (DADM)	Per House Bill Of Lading		CNY	1,085.00
Huom : including Port Surcharge,Tally,EDI,ISPS				
Tuontiselvitys lisänimikkeet (DCAL)	Per Additional Line		CNY	55.00
Tuontiselvitys (DCLE)	Per Entry		CNY	535.00
Toimitustilaus (DDOR)	Per House Bill Of Lading		CNY	550.00
Terminaalikulut (DTHF)	Minimum (Per Shipment)		CNY	360.00
	Per Weight Measurement		CNY	360.00

Huom : incl ECRS and 7 free storage

Sea freight quotation, part 2/2

DHL Global Forwarding

LCL-hintalaskelma Wartsila Finland Oy
Tarjousnumero: HEL_6939_SSQ_599418
Voimassaoloaika: 01 huh. 2019 - 30 huh. 2019

Päiväys: 01 huh. 2019

Sopimus astuu voimaan ilmoitettuanne tarjouksen hyväksymisestä allekirjoittaneelle ja koskee kaikkia lähetyksiä, joiden toimeksianto annetaan hyväksymisen jälkeen. Hyväksymällä tämän tarjouksen sopimukseksi, valtuutatte DHL:n toimimaan tulliedustajananne. Toimeksiannon yhteydessä pyydämme ilmoittamaan tämän tarjouksen numeron.

Attn:	Teemu Lakka teemu.lakka@wartsila.com	Myyntikontakti:	Jari Kiukkonen jari.kiukkonen@dhl.com Tel. +358 40 5127671	Tarjouksen tekijä:	Jari Kiukkonen jari.kiukkonen@dhl.com Tel. +358 40 5127671

LÄHETYKSEN TIEDOT

Lähtösatama/-terminaali:	Helsinki (FIHEL), Finland	Saapumissatama/-terminaali:	Tianjin (CNTSN), China
Palvelu:	LCL GENERAL	Lähdöt per kuukausi:	4
		Kuljetusaika – arvio:	51 päivä(ä) (CFS to CFS)
		Tavara:	GENERAL CARGO

Lähetyksen tiedot

Kollimäärä	Tilavuus yhteensä (m3)	Todellinen paino yhteensä (kg)	Rahdituspaino yhteensä (kg)
0	6.90	2,157.00	6,900.00

Yhteenveto hinnoista

Yhteensä Vientikulut: Helsinki	EUR	554.28
Yhteensä Rahtikulut: Helsinki - Tianjin	EUR	521.82
Yhteensä Tuontikulut: Tianjin	EUR	623.67
Kokonaissumma - Helsinki, Finland - Tianjin, China	**EUR**	**1,699.77**

Air freight quotation

Airfreight charges 2836 EUR + customs clearance 25 EUR. Subject to space and availability upon booking. General cargo, not restricted, stackable/ top loadable. Direct flight from Helsinki to Shanghai airport. Currently space available ex. HEL 3.4.2019, but kindly note that these shipments are being checked with our agent before sending out (in order to avoid additional charges). DAP- charges approx. 921 EUR, excl. duty & VAT, storage, inspections etc.

Best regards
Sarah Cederberg

VAASAHUOLINTA
VASASPEDITION
P.O. Box 1000
FI-65301 VAASA Finland
Visiting addr : Runsorintie 1. FI-65380 VAASA Finland
Tel: + 358 6 3196050
Fax: + 358 6 3121911

Rail freight quotation (Train from Kouvola to Xian)

Oy HACKLIN LOGISTICS Ltd

OFFER / CONTRACT 17700-01

Espoo 15.4.2019

Wärtsilä Solutions Oy
Emanuel Björk
P.O. Box 499
65101 VAASA

Zhangjiagang rahtikysely SP/02924 RAIL LCL

Thank you for your inquiry. We are pleased to offer you as follows:

Service description	Vaasa - Zhangjiagang	
Goods description	29 cll 2156,24 kg, 6,898 cbm, non haz, fully stackable	
	Vaasa - 21563 Zhangjiagang bi-weekly departures Rail Kouvola - Xian T/T approx 28 days door-door	EUR 1865,00/shipment
	Docs	EUR 150,00/B/L
	Export Clearance	EUR 75,00/Invoice
	Customs clearance in Xian (none inspection cargo)	EUR 120,00/Clearance
Project total:		
	.	EUR 2210,00/shipment

Rail freight quotation (Train from Hamburg to Zengzhou)

Oy HACKLIN LOGISTICS Ltd OFFER / CONTRACT 17518-01

Espoo 29.3.2019

Wärtsilä Solutions Oy
Teemu Lakka
P.O. Box 499
65101 VAASA

Zhangjiagang rahtikysely SP/02924 RAIL LCL

Thank you for your inquiry. We are pleased to offer you as follows:

Service description	Vaasa - Zhangjiagang	
Goods description	29 cll 2156,24 kg, 6,898 cbm, non haz, fully stackable	
	Hamburg - Zhengshou 3-4 departures per week T/T approx 16-18 days	EUR 850,00/shipment
	Docs	EUR 150,00/B/L
	Export Clearance	EUR 75,00/Invoice
	Pick up FOT Vaasa - FOT Hamburg as part cargo, 29 kll, 2157 kg, 3,3 lvm (direct full truck is EUR 1600,-)	EUR 810,00/shipment
	Zhengzhou - Zhangjiagang	EUR 380,00/shipment
	Customs clearance in Zhengzhou (none inspection cargo)	EUR 75,00/Clearance
Project total:		
	.	EUR 2340,00/shipment