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UNIVERSITY OF VAASA

Adelina Ragnäs

Different freight options for Wärtsilä Catalyst Systems

A study of transport savings related to costs, transit time and emissions

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Author: Adelina Ragnäs
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ABSTRACT:
Sustainability is constantly becoming more important in today's world and the transport sector is not an exception. Sustainability and reducing greenhouse gas emissions are important for not only the case company, and the governments around the world, but especially also for the environment itself. The purpose of this thesis is to study the differences in transportation costs, environmental impacts (CO_2e emissions) and transit time if choosing suppliers located in Europe or Asia for projects located in Europe or Asia. The aim is also to study how much Wärtsilä Catalyst Systems could reduce their transportation costs and transit time, and how much lower the transport emissions eventually would be if selecting suppliers located in Europe for European projects and suppliers located in Asia for Asian projects.

A case study has been conducted for three different sized projects including three different shipments: NOR reactor and mixing, NOR elements and NOR aux, loose, and spares. For every shipment the transportation costs, CO_2e emissions, and transit time has been calculated for two different departure points and three different destination points. A quantitative research method has been applied to this thesis. Seven different forwarding companies have been asked to provide quotations (including price, CO_2e emissions and transit time) for the different routes. The CO_2e emissions have also been calculated by using the NTM Calc basic 4.0 tool.

The study shows that Wärtsilä can reduce their transportation costs up to 70 000 € for one single shipment if selecting Asian suppliers for Asian project and European suppliers for European projects. For the largest project (case 3), the CO_2e emissions are 3 600 % higher if using European suppliers instead of Asian suppliers when the project is to be delivered to China, Asia. When it comes to the transit time, sea transportation between Europe and Asia takes approximately 45 – 60 days for, while transportation within the continent can usually be arranged within 1 – 5 days. If air transport is necessary for a NOR aux, loose, and spares shipment from Europe to Asia, the transit time can be reduced to 1 – 5 days, but the CO_2e emissions will increase by 5 000 %. Depending on the size of the shipment, the price will also increase by 1 000 – 3 000 €.

KEYWORDS: sustainability, sustainable transportation, greenhouse gases, CO_2e emissions, freight transport modes

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ABSTRAKT:
Hållbarhet blir ständigt viktigare i dagens värld och transportsektorn är inget undantag. Hållbarhet och minskning av växthusgasutsläpp är viktigt inte bara för det aktuella företaget och regeringarna runt om i världen, utan också för miljön i sig. Syftet med denna avhandling är att studera skillnaderna i transportkostnader, miljöpåverkan (CO2e utsläpp) och transporttid om man väljer leverantörer i Europa eller Asien för projekt som är belägna i Europa eller Asien. Målet är också att studera hur mycket Wärtsilä Catalyst Systems kan minska sina transportkostnader och transporttiden, och hur mycket lägre transportutsläppen skulle bli om man väljer leverantörer i Europa för projekt i Europa och leverantörer i Asien för projekt i Asien.

En fallstudie har genomförts för tre olika stora projekt som alla inkluderar tre olika försändelser: ”NOR reactor and mixing”, ”NOR elements” och ”NOR aux, loose, and spares”. För varje försändelse har transportkostnaderna, CO2e utsläppen och transporttiden beräknats för två olika avreseorter och tre olika destinationer. En kvantitativ forskningsmetod har tillämpats i denna avhandling. Sju olika speditörsföretag har ombetts att lämna anbud (inklusive pris, CO2e utsläpp och transporttid) för de olika rutterna. CO2e utsläppen har också beräknats med hjälp av internetverktyget ”NTM Calc basic 4.0”.

Studien visar att Wärtsilä kan minska sina transportkostnader med upp till 70 000 € för en enskild försändelse om man väljer leverantörer i Asien för projekt i Asien och europeiska leverantörer för projekt i Europa. För det största projektet (projekt 3) är CO2e utsläppen 3 600 % högre om man använder europeiska leverantörer istället för asiatiska leverantörer när projektet ska levereras till Kina, Asien. När det gäller transporttiden tar sjötransporten mellan Europa och Asien cirka 45 – 60 dagar, medan transporten inom kontinentenrna i fråga vanligtvis kan ordnas inom 1 – 5 dagar. Om lufttransport är nödvändig för en försändelse av ”NOR aux, loose and spares” från Europa till Asien kan transporttiden minskas till 1-5 dagar, men CO2e utsläppen ökar med cirka 5 000 %. Beroende på försändelsens storlek kommer även priset att öka med 1 000 – 3 000 €.

NYCKELORD: hållbarhet, hållbar transport, växthusgaser, CO_2e utsläpp, godstransportsätt

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Abbreviations

CO_2	Carbon Dioxide
CO_2e	Corbon Dioxide Equivalent
DC	Dry Container
DV	Dry Van Container
EEA	European Environment Agency
FR	Flat Rack Container
GHG	Greenhouse Gas
GP	General Purpose Container
GWP	Global Warming Potential
HC	High Cube Container
HQ	High Cube Container
ISO	International Organization for Standardization
LTL	Less-than-truckload
FTL	Full truckload
N_2O	Nitrous Oxide
NOR	Nitrogen Oxides Reducer
NOx	Nitrogen Oxide
NTM	Network of Transport Measures
RFQ	Request for Quotation
RORO	Roll-on/roll-off
SCR	Selective Catalytic Reactor
WTO	World Trade Organization

1 Introduction

With all the transport modes included, the transport sector contributes to 25 % of the carbon dioxide (CO_2) emissions in the world (Rodrigue, 2024). At the same time, the transport sector is one of the only sectors in the European Union where the emissions are still higher than they were 30 years ago. Within the transport sector, the biggest emitter is the road transport that in year 2019 contributed to more than 70 % of all greenhouse gas emissions from transport (European Commission, n.d.-e).

Greenhouse gases (GHGs) that are released to the atmosphere are not the only harmful consequences of the transport sector. Transport is also a key source of air pollutants and noise (European Environment Agency, 2023a). The transport sector is one of many sectors that contribute to climate change, and the human activities and choices have a great impact as well. According to Tiefenbacher (2020) global warming might be the biggest threat we are facing today regarding climate change, but also acidifying oceans, mismatches between hydrological patterns, and extreme weather events are direct effects of climate change.

In 1977, the value of global exports did for the first time exceed 1 trillion US dollars, and in 2008 the same value had increased to over 16 trillion US dollars. Almost 15 years later, in 2022, the value of the global exceeded 25 trillion US dollars (Rodrigue, 2024). This means that in 45 years, the value of global exports had increased by 2400 %. At the same time, the freight transportation has undoubtedly also increased. 1,06 gigatons (1 060 000 000 000,00 kg) of CO_2 emissions was in 2018 caused by shipping. A GHG strategy by the International Maritime Sector (IMO) aims to reduce the CO_2 emissions from the shipping industry by 40 % by year 2030 and 70 % by year 2050 compared to the levels of 2008. (Aakko-Saksa et al., 2023)

The four main freight modal options are air, road, rail, and maritime. Which freight method to be chosen when is being decided by many different aspects. In order to be able to choose the most suitable freight option, factors like delivery distance, size of load, shipping price, and urgency need to be taken into consideration. (Rodrigue, 2024)

1.1 Background and purpose

This thesis is being conducted for an organisation in Wärtsilä named Catalyst Systems. Catalyst Systems is not manufacturing the components of their selective catalytic reactor (SCR) technologies including the nitrogen oxides reducer (NOR) product themselves, but these are being ordered from different suppliers located in both Europe and Asia. However, the design is being owned and developed by Wärtsilä. When it comes to the transportation, the NOR deliveries are usually being divided into three different shipments: NOR reactor and mixing, NOR elements and NOR aux, loose, and spares. This far, all NOR aux, loose, and spares components have been manufactured in Europe and factory acceptance test (FAT) has been done in Vaasa, Finland. Around 50 % of Catalyst Systems' projects are being delivered to Asia, meaning the Asian market is of great importance to Catalyst Systems. Upon customers' requirements, the possibility of Asian suppliers for NOR aux, loose, and spares components are now under investigation. Suppliers for NOR reactor and mixing and NOR elements are already located in both Europe and Asia, and in addition to the price of the units, technical requirements and delivery time is also being considered when the selection of supplier is being made.

The purpose of this research is to study the differences in transportation costs, environmental impacts and transit time if selecting suppliers located in Europe or Asia for projects located in Europe or Asia. The purpose is also to study how much Catalyst Systems could reduce their transportation costs and delivery time, and how much lower the transport emissions eventually would be if selecting suppliers located in Europe for European projects and suppliers located in Asia for Asian projects. In some exceptional cases, a shipment can also be sent by air from Finland to Asia and this is also a scenario where transportation costs, environmental impacts and delivery time will be studied.

1.2 Research questions and objectives

According to the purpose of this thesis, the primary goal is to compare the different shipment scenarios to each other based on their costs, environmental impacts, and delivery time. Road freight and sea freight are the two main transportation modes studied, but for some scenarios also air freight will be examined. The research question is defined as following:

- "How much can Catalyst Systems reduce their transportation costs, environmental impacts, and delivery time?"

In the third chapter, a literature review is conducted to provide the reader the fundamentals of transportation and its impact on the environment. A quantitative research method will be used to conduct the study, and the nature of the research is an empirical study.

1.3 Scope and limitations

The thesis is limited to studying only three different size of projects that are typical for Wärtsilä Catalyst Systems NOR deliveries. A NOR project is typically divided into three different shipments: NOR reactor and mixing, NOR elements and NOR aux, loose, and spares. For all these three shipments, the same three destination points will be applied. These destination points are three shipyards (one in Europe and two in Asia) that are appreciated customers to Wärtsilä. The shipyards are:

- Hudong–Zhonghua (HDZH) Shipbuilding – located in China
- Hanwha Ocean Co., Ltd – located in South Korea
- Fincantieri S.p.A – located in Italy

For NOR reactor and mixing, the transportation from two different departure points is being studied. The departure points are the manufacturers' locations, and one is located in Maardu, Estonia and one is located in Suzhou, China. The three different projects' size is being specified below:

- Case 1 NOR reactor + mixing

  Total cases: 8
  Gross Weight (kg): 14258,00
  Vol (m^3): 114,775

- Case 2 NOR reactor + mixing

  Total cases: 10
  Gross Weight (kg): 26147,00
  Vol (m^3): 205,671

- Case 3 NOR reactor + mixing

  Total cases: 10
  Gross Weight (kg): 51285,00
  Vol (m^3): 335,377

For NOR elements, the transportation from two different departure points is being studied. The departure points are the manufacturers' locations, and for NOR elements one is located in Redwitz, Germany and one is located in Gyeongbuk, South Korea. For NOR elements, the size of the shipments of the three projects are following:

- Case 1 NOR elements

  Total cases: 12
  Gross Weight (kg): 5856,00
  Vol (m^3): 14,950

- Case 2 elements

  Total cases: 22
  Gross Weight (kg): 10550,00
  Vol (m^3): 27,408

- Case 3 NOR elements

  Total cases: 41
  Gross Weight (kg): 32821,00
  Vol (m^3): 78,755

NOR aux, loose, and spares shipments are having three different departure points in this study. One is a consolidation point, and the other two are two different Wärtsilä premises. The departure points are in Pori, Finland, Suzhou, China and Vaasa, Finland. For this thesis, the transportation of NOR aux, loose, and spares from Vaasa is only being considered as air freight to China and South Korea in urgent situations. For the destination point in Italy, only departure point Pori, Finland is applied. For NOR aux, loose, and spares, the size of the shipments for case 1 and case 2 were so similar to each other, that it was decided to leave case 2 out of the study. Therefore, only case 1 and case 3 is being studied for NOR aux, loose, and spares, and their sizes are specified below:

- Case 1 NOR aux + loose + spares

  Total cases: 10
  Gross Weight (kg): 1435,00
  Vol (m^3): 7,381

- Case 3 NOR aux + loose + spares

  Total cases: 18
  Gross Weight (kg): 3123,00
  Vol (m^3): 15,635

1.4 Structure of the thesis

In chapter 2, the case company Wärtsilä Finland Oy and their organization Catalyst Systems will be introduced as well as a short presentation of their products. Chapter 3 provides a literature review of sustainability, sustainable transportation, and the environmental impacts of transportation. Different transportation modes and their greenhouse gas emissions will also be included in the literature review. In chapter 4, the research strategy will be presented, followed by a presentation of the data collection and analysis. Chapter 5 describes how the research was done in detail and presents the results of the research. Finally, chapter 6 provides conclusions and discussions of the results, including the reliability, as well as suggestions for future research related to the topic.

2 Case company

The case company for this thesis, Wärtsilä, was founded in 1834 meaning they are celebrating their 190th anniversary this year. In both marine and energy markets, Wärtsilä is a global leader when it comes to lifecycle solutions and innovational technologies. In year 2024, Wärtsilä has almost 18 000 employees in 79 countries around the world. (Wärtsilä, n.d.-g). Their business is divided into three main business areas: Wärtsilä Energy, Wärtsilä Marine, and Wärtsilä Portfolio Business. The order intake for these three businesses together in 2023 was 6,417 million euros and their net sales was 5,524 million euros. (Wärtsilä, n.d.-c)

Sustainability is a core value for Wärtsilä, and they are providing their customers environmentally friendly solutions and promoting responsible business practices in order to contribute to a sustainable future (Wärtsilä, n.d.-d). Wärtsilä's goal is to become carbon neutral in their own operations by 2030 (Wärtsilä, n.d.-a). Therefore, decarbonisation is of great importance in their products and product portfolio development. Some key features of Wärtsilä's environmental solutions are low emissions and noise levels, high efficiency, fuel flexibility, compliance with environmental regulations and lifecycle optimization. (Wärtsilä, n.d.-b)

Wärtsilä Marine offers their customers a solution to present challenges within the marine sector. Their core standalone products are engines and propulsions, while catalysts (NOx reducers) are a key complementary technology. Wärtsilä can provide a strong solution for each vessel, including engine optimisation and fuel flexibility, electrification, energy saving devices and lifecycle solutions. (Wärtsilä, n.d.-e)

According to their website, Wärtsilä describes their NOR system in following way: "The Wärtsilä NOx Reducer (NOR) is an emission after-treatment system based on the Selective Catalytic Reduction (SCR) technology for Nitrogen Oxides (NOx) reduction." (Wärtsilä, n.d.-d) This means that the NOx reducer reduces the emissions of nitrogen oxides, which is a hazardous pollutant, from combustion processes. NOx contributes to air pollution which means that it can affect the human health and environment negatively. Through several chemical reactions, NOx is being converted into less hazardous substances by the NOR system. This NOR product is available for both newbuild projects and retrofit projects and is able to be operated on both traditional fuels and new sustainable fuels. When it comes to both the reliability and easy installation, Wärtsilä's NOR product is optimized for their medium-speed engines. Not only the emissions reduction is being optimized with the NOR product, but also the engine efficiency and noise reduction is being optimised. As a package including both engine and SCR unit, Wärtsilä provides IMO and EPA Tier III EIAPP certificates. (Wärtsilä, n.d.-f)

The NOR system's main component is the reactor, including a soot blowing unit and the catalyst elements. Other essential components of the NOR system are Urea pump unit, Urea dosing unit, Urea mixing and injection unit. This is being visualized in figure 1 on page 16, together with a Wärtsilä engine. (Wärtsilä, n.d.-f)

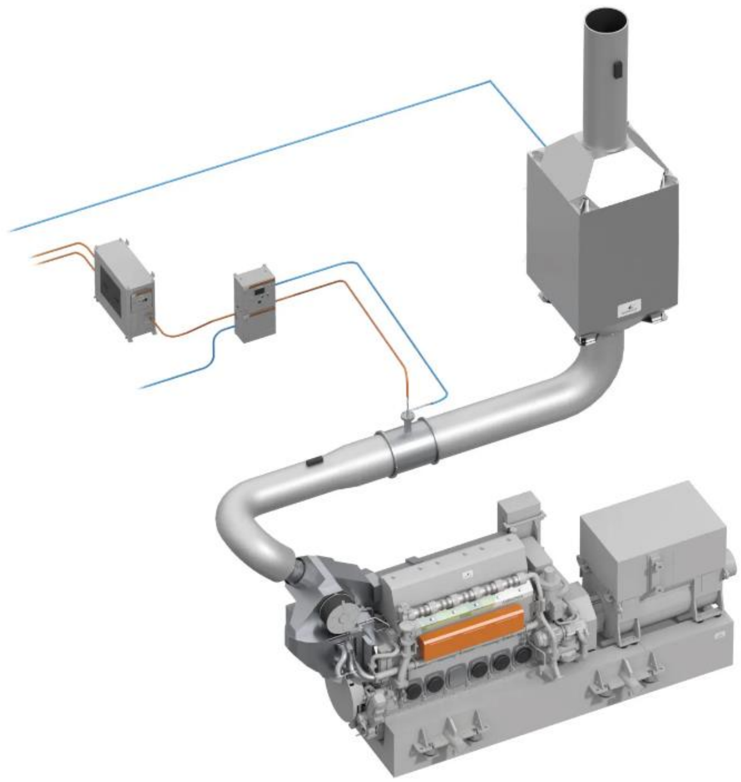

Figure 1. The NOR installation together with a Wärtsilä engine. (Wärtsilä, n.d.-f)

3 Literature review

In this chapter, the current literature related to sustainability and sustainable transportation are being reviewed. An introduction of global warming, climate changes and greenhouse gases will also be given. Further, different freight methods, combined transport and the impact on the environment caused by transportation will be presented. The purpose of this chapter is to present a comprehensive understanding of the global transport industry today and its environmental impacts.

3.1 Sustainability and sustainable development

Sustainability and sustainable development are often being used as synonyms to each other and the concept is widely known as a reference for scientific research on the environment (Ruggerio, 2021). Sustainable development meets the needs of today, without any compromises on the ability for the generations to come (Black, 1996). According to Ukko et al. (2019), to gain competitive advantage in a business or an organisation, traditional innovations are needed. They state that examples of traditional innovations are the development of a service, product, or process. On the other hand, sustainable innovations, for example completely new products, new ideas of the processes and services, are needed in order to try to solve the environmental challenges (Ukko et al., 2019). The terms sustainability and sustainable development are often being used in questions related to business, industries, agricultural production, and urban development (Ruggerio, 2021).

In the report *Our Common Future* that the World Commission on Environment and Development published in 1987, the term sustainable development was defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environnent and Development, 1987, p. 41). The report is also known as the “Brundtland Report” after the commission’s chairwoman Gro Harlem Brundtland (Elkington, 1997).

This report developed the basics of sustainable development as it is still generally understood today. In 1997, Elkington established the triple bottom line theory as an extension to this definition of sustainability. According to the triple bottom line theory, sustainability consists of three different elements where all elements are equally important. These three elements are economic, social, and environmental. (Elkington, 1997)

Figure 2. The interconnection of the three elements included in the Triple Bottom Line concept. (Dalibozhko & Krakovetskaya, 2018)

The triple bottom line concept has been described as the basis of sustainability and the this concept is also known as triple-P (people, planet, profit) (Dalibozhko & Krakovetskaya, 2018; Elkington, 1997). In figure 2, the relationship between the elements of sustainability is shown graphically. Dalibozhko & Krakovetskaya (2018) describes the three elements in following way:

People: also known as the social dimension. This is about the corporate responsibility. This element can be described as the impact and effect organizations have on the involved communities.
Planet: also known as the environmental dimension. This element focuses on the impacts on the environment such as land, air, water, and ecosystems.
Profit: also known as the economic dimension. This element focuses on the enterprise level's financial impact, for instance the usage of resources in an efficient way, cost savings, product advantage and the creation of new jobs.

The 193 member states of the United Nations did in 2015 publish a brand-new agenda named "Transforming our world: The 2030 agenda for sustainable development" (United Nations, 2015). This agenda is an action plan for the world's sustainable development, including the economic, social, and environmental dimensions. The document consists of 17 sustainable development goals and 169 targets for its five main elements: people, planet, prosperity, peace, and partnership. The aims of the goals and targets are to protect the planet, defend the human rights and gender equality, and encourage peace. (United Nations, 2015)

"The interlinkages and integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is realized. If we realize our ambitions across the full extent of the Agenda, the lives of all will be profoundly improved and our world will be transformed for the better." (United Nations, 2015, p. 2)

3.2 Sustainable transportation

In 1996, William R Black defined sustainable transportation as "satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs". (Black, 1996). Evans (2011) states that sustainable transportation and green transportation are sometimes used as synonyms to each other. Further, he highlights that these terms include all transports that have a low or negative effect on our planet, because sustainable energy sources are being used instead of fossil fuels. Green transport relies on renewable energy instead of dwindling natural resources (Evans, 2011). Controlling energy consumption and pollution are two important factors when speaking about sustainable transportation. The aim is also to improve the planet's liveability and economic well-being. (Rajak et al., 2016). According to Rajak et al. (2016) the four major dimensions of sustainable transportation are environmental sustainability, social sustainability, economic sustainability, and transportation system effectiveness.

According to Andersson et al. (2020) significant changes in technology and behaviour are necessary for the transport industry to become more sustainable. It is important for the persons who are responsible for formulating policies to understand the choices the general population do related to green alternatives in transportation. When understanding this, it is easier to create well planned and efficient policies for the future. (Andersson et al., 2020). The easiest way for the general population to use green and sustainable transportation is to choose to walk or bicycle when possible (Evans, 2011).

In previous chapter, it was stated that sustainable development can be divided into three different dimensions; economic, social, and environmental. According to Rodrigue (2024) sustainable transportation can be divided into the same three dimensions, more precise; environmental protection, social progress, and economic efficiency. He furthers states that improvements in efficient, safety and the environment are therefore also expected outcomes of sustainable transportation. The objectives of the three different dimensions are in short presented below:

> Environmental dimension: environmental issues and challenges need to be addressed by all parts of the transport industry. Another objective is to understand the mutually effects of the environment and the industry's practices.
>
> Social dimension: improve quality of life and living standards.
>
> Economic dimensions: cost-effective transportations which are also able to adapt to changing demands. Another objective is to encourage economic efficiency by developing mobility systems and infrastructures. (Rodrigue, 2024, chapter 4)

A long-term goal for the European Union is a non-polluting and decarbonised system (European Environment Agency, 2023a). In December 2021, the decarbonised gases and hydrogen package was put forward by the Commission as a part of the European Green Deal (European Commission, 2023). This package is of high importance to reach the two main goals under the European Climate Law; to become climate-neutral by 2050 and to reduce greenhouse gas emissions by minimum 55 % by 2030 compared to 1990 level (European Commission, n.d.-b). Transport is a primary source when it comes to pressures of the environment in Europe. These pressures are for instance greenhouse gases and air pollutants. Further, transport requires a good infrastructure, which at the same time leads to urban sprawl. (European Environment Agency, 2023a). In 2022, 21,6 % of all new car registrations in the EU were electric vehicles (European Environment Agency, 2023c). This percentage is the highest it has been so far, and the percentage has been constantly increasing since 2016. As it is shown in figure 3, battery electric cars increased by almost 25 % from 2021 to 2022, while the percentage of plug-in hybrid cars remained stable.

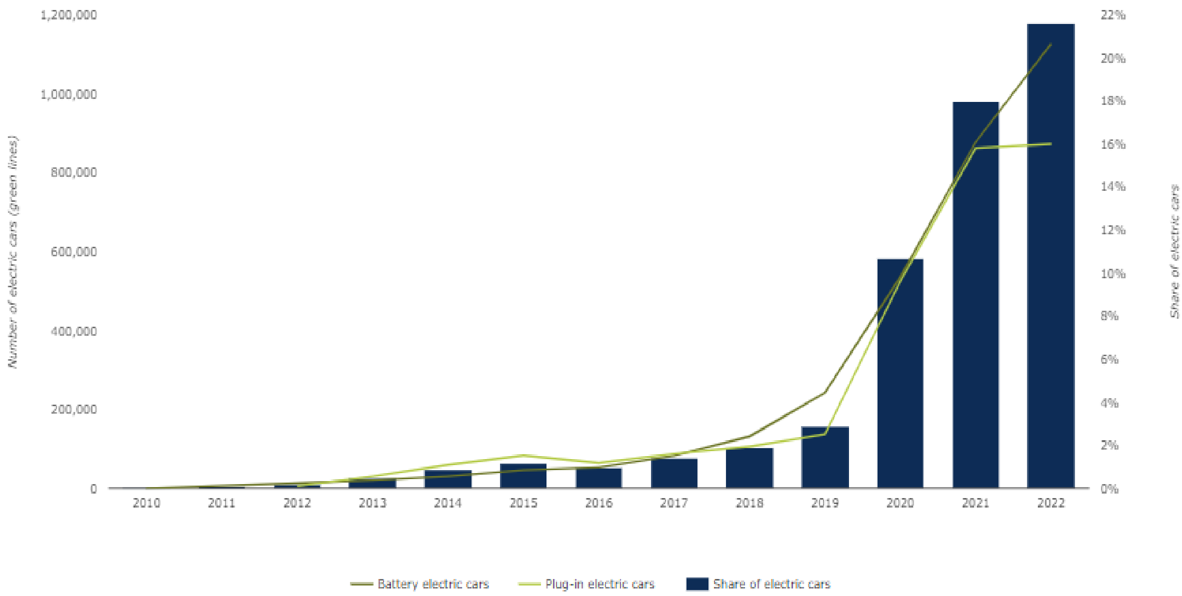

Figure 3. New electric car registrations from 2010 – 2022. (European Environment Agency, 2023b)

To increase the transparency on the environmental sustainability performance of transport companies and logistics hubs, calculating and specifying greenhouse gas (GHG) emissions have become a main method (Dobers et al., 2023). Calculating GHG emissions and energy consumption were done in many different ways, which led to the need to develop a standardized method (Petro & Konečný, 2017). In 2013, the European standard EN 16258 *Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers)* was published by the European Committee for Standardisation (CEN) (European Committee for Standardisation, 2013).

In year 2023, ISO (the International Organization for Standardization) did publish their newly developed ISO 14083 standard (International Organization for Standardization, 2023), which provides a common methodology for operations within the transport chain (both freight and passengers) to calculate and report their GHG emissions (Yavari et al., 2023). ISO 14083 replaces the earlier European Standard EN 16258 and is expected to be a significant step forward for GHG emissions reporting in the transport sector worldwide.

NTM (Network of Transport Measures) did in year 2000 become a member of the Technical Committee ISO/TC 207 – Environmental management. This membership gave NTM the opportunity to take part in the development of the new international standard ISO 14083 - *Quantification and reporting of greenhouse gas emissions of transport operations*. Their aim of the participating in the work to develop ISO 14083 was to contribute to the useful international standard that can support their members in general and in particular also to apply the standard in their environmental performance calculator NTM Calculation. (Network of Transport Measures, 2020)

3.3 Evolution of the global trade

Global export did increase significantly in 1990 due to the enormous offshoring of manufacturing (especially in China) and the fast industrialization in developing economies. In

1977, for the first time in history, the total value of global exports overpassed one trillion US dollars. Almost 30 years later, in 2008, the value had increased to more than 16 billion US dollars. During these 30 years, the world GDP (considered both import and export of goods) increased also from 18 % to 52 %. (Rodrigue, 2024, chapter 7) .

The World Trade Organization (WTO) points out that the world trade volume has increased by 4500 % since the creation of the General Agreement on Tariffs and Trade (GATT), in other words from 1950 until 2022 (World Trade Organization, n.d.).

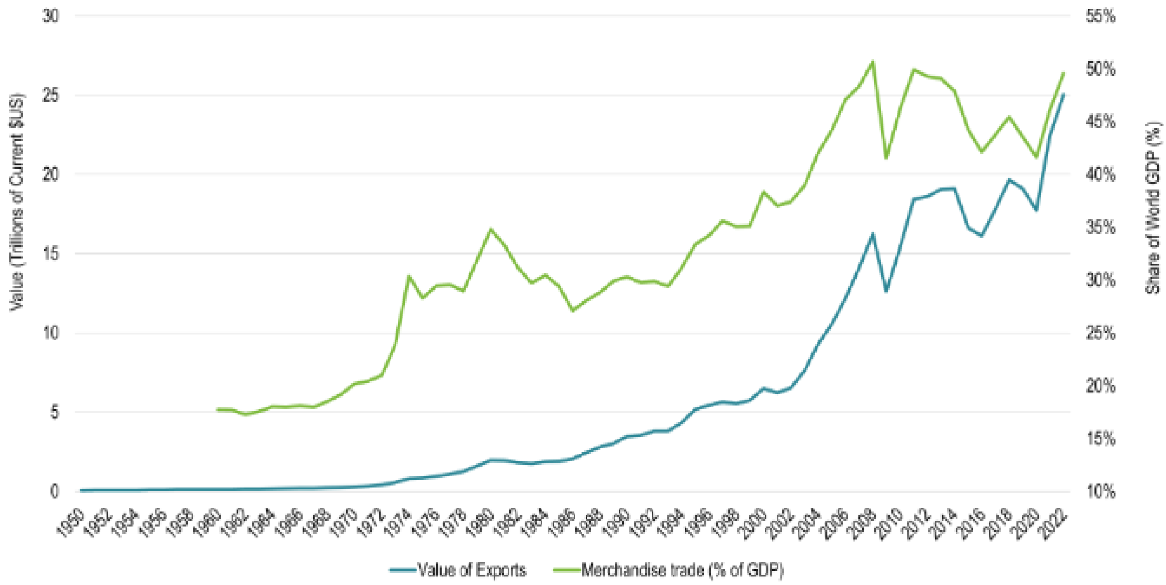

Figure 4. World merchandise trade and the value of export 1960-2022. (Rodrigue, 2024)

In figure 4, the world merchandise trade and the value of export from 1960 to 2022 is being shown. From 1960 until 1975, the trade and export had its appearance and according to figure 4, the value of exports were of no significant important. From 1975 until 2002, it can be stated the trade and value of exports were accelerating steadily. China officially became a member of WTO on December 11, 2001 (World Trade Organization, 2020). According to Wolff (World Trade Organization, 2020) China's accession to the WTO in late 2001 had a crucial impact on the global trade, which accelerated due to the growth of Chinese export. Wolff (World Trade Organization, 2020) also points out the financial crisis in 2008 and 2009 where the decline in the global merchandise trade was significant. In only one year, the decline was almost 25 %. Wolff also states that even if Covid-19 pandemic lead to a decline in global trade in 2020, it recovered quickly in 2021 due to the postponed demand (World Trade Organization, 2020).

3.4 Climate change

Warning messages concerning climate change are becoming more and more important and serious all the time. To be able to reduce the threat of climate change, all potential activities are necessary (Aakko-Saksa et al., 2023). Amini (2019 p. XI) states in the preface of his book *Climate Change and Global Warming* that "It is now generally accepted that social movements are changing the configuration of our ecosystem. However, misperceptions of the solutions are increasing".

It is not possible to avoid all negative impacts of the climate change from today onwards, but the most powerful influences can be prevented. That will result in a more manageable and pleasant life for everyone. However, decisive, and major actions need to be taken already today. (Amini, 2019)

3.4.1 Global warming

The average surface temperature on our earth was in 2023 the warmest it has even been since recordkeeping began in 1880. Earth is approximately 1,4 degrees Celsius warmer today than it was in the late 19th-century, before the global industrialization. From 2010 until 2023 the average surface temperature has increased from 0,65 degrees Celsius to 1,01 degrees Celsius. This also means that the ten warmest years on record are also the ten most recent years. (NASA, n.d.)

According to these numbers, global warming is no humbug. Tiefenbacher (2020) says that we for sure do not know everything about global warming yet, but there's no doubt about the existence of the phenomenon and that human activities are the main reason to the enormous increase in levels of GHGs over the last 200 years.

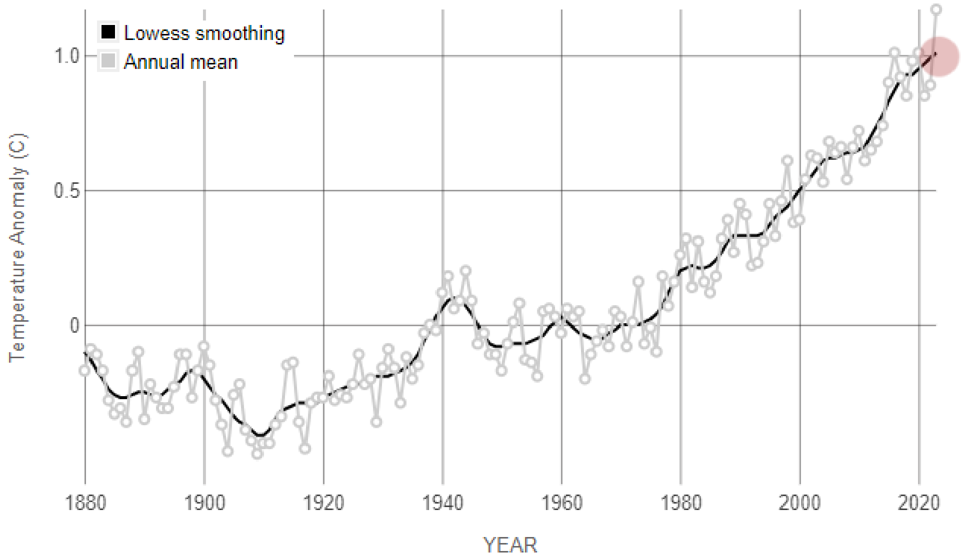

Figure 5. Global surface temperature between 1880 and 2023. (NASA, n.d.)

Changes in the climate and an increased average surface temperature are only two of many complications that both the earth and we humans are facing due to global warming. Other complications that Tiefenbacher (2020) highlights are:

- Reduced areas of components of the cryosphere (for instance glaciers, permafrost, Antarctica's ice cap and Greenland's ice sheet)
- Changing habitat sizes; declining for native species and increasing for invasive species
- Ecological systems being subverted, especially coral reefs
- Mismatches between climates and soils, plant and animal life, and weather processes (for instance humidity and cloud cover)
- Rising sea levels and ocean acidification
- Changing dispensations of saltwater and freshwater
- Diseases that have been limited because of previous climate conditions can now be spread.

The earth's climate will always have an impact on humans. During the last decades, technologies of modern industrial societies have had a significant impact on human life, but that does not decrease the influence of climate. The complications which are listed earlier in this chapter, do have a direct or indirect threat on our health by having an impact on the food we eat, the water we drink, the air we breathe and the energy we use. With this said, global warming as well as climate changes affect human life. Vice versa, do human life also affect climate. (Amini, 2019)

3.4.2 Greenhouse gases

A greenhouse gas (GHG) is a gas that traps heat in the atmosphere. More exactly, it absorbs infrared radiation and therefore it contributes to the greenhouse effect. A GHG can be natural or caused by human activities. The natural GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (H_2O), and ozone (O_3). However, specific human activities are contributing to the levels of most of these gases as well. (US Department of Transportation, 2016)

Carbon dioxide comes into the atmosphere through burning solid waste, fossil fuels (natural gas, oil, and coal), and wood. During the production of cement (and other specific chemical reactions), carbon dioxide is also emitted. Carbon dioxide leaves the atmosphere when plants use it in the photosynthesis. (US EPA, 2024)

Methane comes into the atmosphere during the production and transport of natural gas, oil, and coal. It is also emitted from the decay of organic materials, for example manure, sewage sludge or biodegradable waste. Methane is also emitted from the digestion of pets and livestock. The two main sources that emit nitrous oxide to the atmosphere are agricultural and industrial activities. (US Department of Transportation, 2016). Also, during wastewater treatment and during the combustion of fossil fuels, nitrous oxide comes into the atmosphere (US EPA, 2024).

Fluorinated gases (F-gases) are artificial and high-powered gases that comes into the atmosphere through industrial processes and household systems, for instance stationary refrigeration, air conditioning, and insulation foams. These gases are totally human-made, and they contribute to global warming as other greenhouse gases. (European Commission, n.d.-a)

Fluorinated gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (US EPA, 2024). Of these, hydrofluorocarbons are the largest emitter and stand for almost 90 % of all fluorinated gases. (European Commission, n.d.-a)

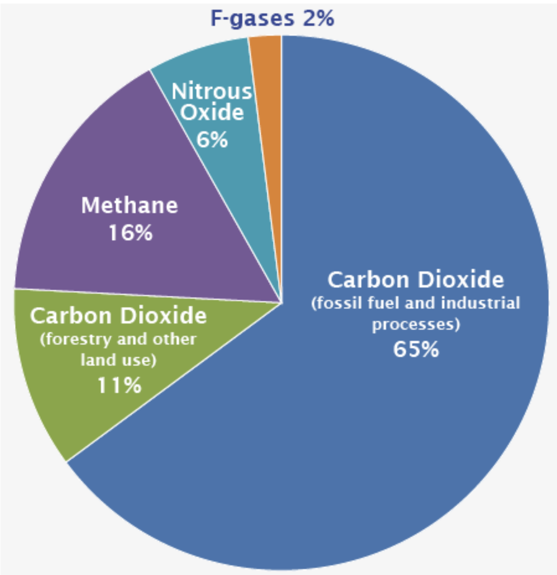

Figure 6. Global greenhouse gas emissions by gas. (MET group, 2021)

3.5 The environmental effects of transportation

Transportation is a vital part when it comes to modern societies and economies. It helps to connect people, cities, and countries with each other. This leads to internationalization and globalization of companies as well as people being able to travel the world and easier get access to employment, healthcare, and education. For many persons, well-developed transport networks lead to e better quality of life. However, there are also drawbacks with our modern transport model. (European Environment Agency, 2024)

Both the environment and human health are facing unfavourable consequences due to the transport sector (Aakko-Saksa et al., 2023 p. 2; Misra et al., 2017). Poor air quality and obesity are only two examples (Aakko-Saksa et al., 2023 p. 2). According to Rodrigue (2024, chapter 4) the environmental impacts caused by the transport sector can be divided into three different categories: direct impacts, indirect impacts, and cumulative impacts. He describes the three different categories in following ways:

1. Direct impacts are the prompt outcomes with damaging effects on the nature, for instance carbon monoxide (CO) emissions and noise. Typical for direct impacts is that the cause-and-effect relationship is logical and easy to understand.
2. Indirect impacts do generally have larger impacts on the nature than direct impacts have, but the involved relationships can be more difficult to understand. For instance, particulates, which are primarily the result of incomplete combustion in internal combustion engines, have been found to have indirect links to respiratory and cardiovascular problems. This is due to their contribution, among other factors, to the development of such conditions.
3. Cumulative impacts are the associational effects of transport activities. Present, past, and future activities (both caused by humans, and natural processes) that have changed the environment belong to this category. The cumulative impact of noise is bad hearing. (Rodrigue, 2024)

3.6 Greenhouse gas emissions from transport

The transport sector contributes to almost 25 % of all GHG emissions in Europe. In addition, transport is also the major source of air pollution in cities. With this said, the emissions from the transport sector are still exceeding 1990 levels as one of the only sectors within the EU economy with that trend. (European Commission, n.d.-e)

The transport emissions need to decrease by 90 % by 2050 in order to reach climate neutrality (European Commission, n.d.-e), which is one of the main goals of the European climate law (European Commission, n.d.-b). According to the European Commission (n.d.-c) Transportation by road is within the transport sector the largest emitter, since 70 % of all transport GHG emissions in 2019 was caused by road transport. To be able to reach the climate neutrality goal by 2050, transport emissions need to be reduced in all transport sectors; road, rail, air, and maritime transport sectors. (European Commission, n.d.-e)

In figure 7 on page 30, the GHG emissions from all domestic transport in Europe from 1990 to 2022 is being shown. From 2013 until 2019 there was a steady increase in GHG emissions, but in 2020 these dropped significantly by 13.5 %. The reason behind this drop according to the European Environment Agency (EEA) is the reduced activity during the COVID-19 pandemic. In 2021, the negative trend had again turned positive, and the GHG emissions had increased by 8.6 % and the growth continued in 2022 also when the emissions had increased by 2.7 %. (European Environment Agency, 2023b)

EEA's predictions for 2030 with current measures results in a 4 % GHG emission level above 1990 levels. The Member States of EEA plan to implement additional measures which should lead to a more significant reduction in GHG emissions. With these new measures, GHG emissions level in 2030 are projected to be 5 % below 1990 levels. These planned measures consist mostly of low-carbon fuels and electric cars as well as promoting public transport for the general public. (European Environment Agency, 2023b)

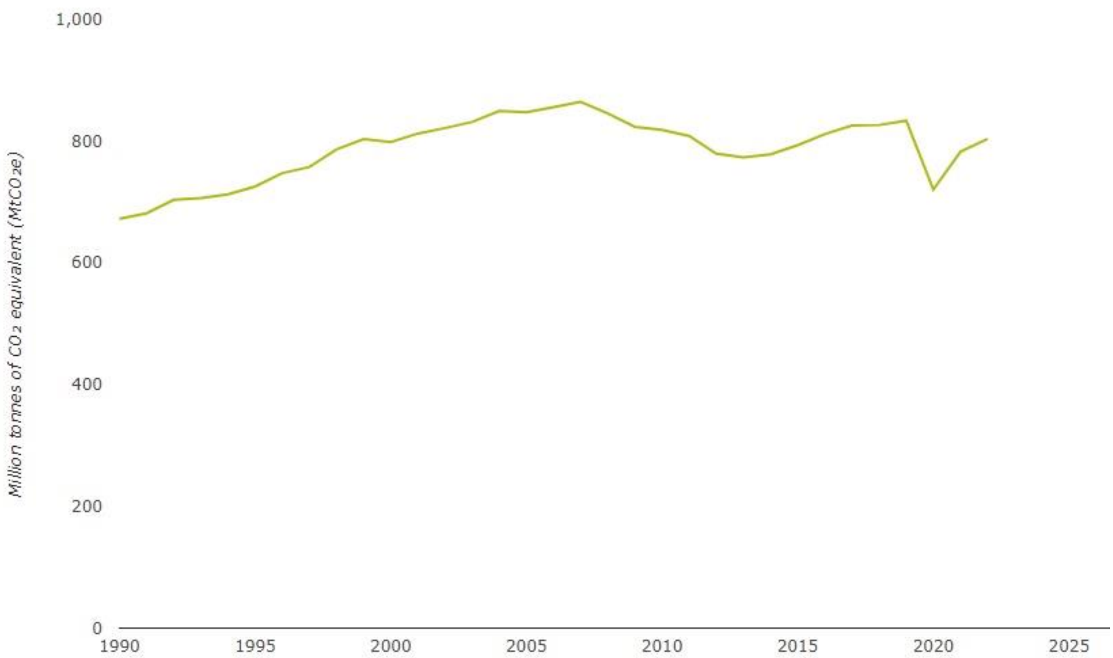

Figure 7. GHG emissions from all domestic transport in Europe from 1990 – 2022. (European Environment Agency, 2023b)

Domestic transport, international air transport and international maritime transport are the three main sources of GHG emissions within the transport sector. Within the domestic transport sector, emissions from domestic sea transport, air transport and railways have been reduced since 1990 and from 2022 onwards the emissions are projected to stay on a relatively stable level. (European Environment Agency, 2023b)

Three quarters of all EU's transport GHG emissions (both domestic transport and international bunkers) in 2021 comes from road transportation. Road transport is the sector that the Member States of the EEA focus most on, which leads to a more significant reduction of GHG emissions in this sector than in other transport sectors. As air transport and maritime transport are not being prioritised by national policies, the GHG emissions from these transport modes are therefore projected to have the largest increase of all transport modes within the next six years. In year 2030, the percentage of transport related GHG emissions from road transport should have decreased while the GHG emissions from other transport modes should have increased. (European Environment Agency, 2023b)

The maritime transport sector represents roughly 80 % by volume, and 70 % by value of global trade (Aakko-Saksa et al., 2023, p.2). With other words, also the maritime shipping sector is a substantial source of greenhouse gas emissions. At the same time, it plays of course also a vital role in the world's economy and the maritime transport is one of the most energy efficient ways of transport. The global CO_2 emissions of shipping in year 2018 was as much as 1076 gigatons (Gt). This amount of CO_2 emissions was 2.9 % of global anthropogenic CO_2 emissions the same year. At EU level in 2021, over 124 Gt of CO_2 was caused by sea transport. Of the EU's total CO_2 emissions in 2021, this represents 3.0 - 4.0 %. (European Commission, n.d.-d)

In figure 8 on page 32, different transport modes' GHG emissions in the EU between 1990 and 2022 and their projection from 2023 until 2040 are being presented. In 2019, there was a significant drop in all transport modes except railways. The largest drop can be found in the international aviation. In 2020, the emissions of international air transport were almost 60 % lower than the previous year's emissions. The reason behind this significant drop is the COVID-19 pandemic. The low level of GHG emissions from international aviation was only temporary. Already in 2021, the number of flights had increased by almost 25 % compared to 2020 and in 2022 the air traffic had increased by almost 50 % compared to 2020. (European Environment Agency, 2023b)

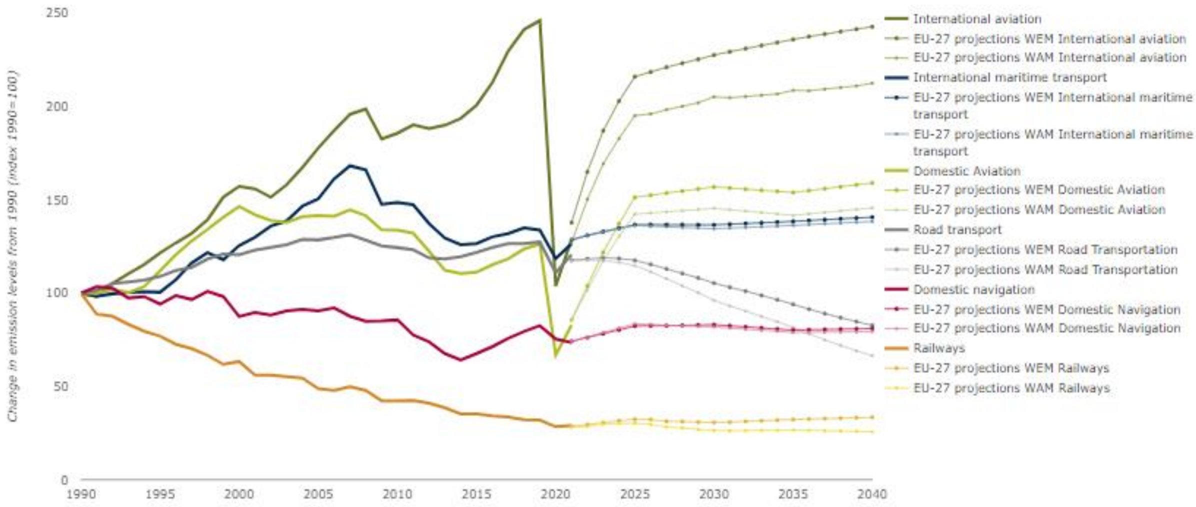

Figure 8. Different transport modes' GHG emissions in the EU between 1990-2022 and their projections until 2040. (European Environment Agency, 2023b)

3.7 Carbon dioxide equivalent

Carbon dioxide equivalent, abbreviated as CO_2-eq or only CO_2e, is a measure that describes what global-warming potential (GWP) a GHG has (Turner & Collins, 2013). According to Turner & Colling (2013), this measure makes it possible to compare the different GHGs to each other. The unit of measure for CO_2-eqs is MMTCDE which means million metric tons of carbon dioxide equivalents (European Environment Agency, 2001). The amount of warming a greenhouse gas is causing over a specified period of time is expressed in GWP, and this time period is usually 100 years (Eurostat, 2023b; Pelletier et al., 2019) .

CO_2 is often considered to be the most important GHG, and in the GWP index CO_2 is having value 1 (Main, 2012). The number of GWP the other GHGs have, means how many times more warming they are causing compared to CO_2. Carbon dioxide equivalent is a very functional and appreciated term as it makes it easy to compare different greenhouse gases based on their global warming impact (Main, 2012). In table 1 it is shown that when it comes to a certain amount of a GHG, CO_2 is having the lowest global warming potential while SF_6 is having the highest.

Table 1. Global warming potential for different greenhouse gases (Metz & Intergovernmental Panel on Climate Change, 2007)

Greenhouse gas	Abbreviation	Global Warming Potential
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous Oxide	N_2O	298
Hydrofluorcarbons	HDCs	124 - 14,800
Perfluorocarbons	PFCs	7,390 - 12,200
Sulfur hexafluoride	SF_6	22,800
Nitrogen trifluoride	NF_3	17,200

3.8 Different transportation modes

There are a wide range of transport modes in today's world, and these can be divided into three main categories based on what surface they travel over. These three categories are land, water and air and they are all adopted to meet the customer's demand, regardless of concerning freight or passenger traffic. Further, the land category can be grouped into three different subcategories: road, rail, and pipelines. (Rodrigue, 2024, p. 127)

In figure 9, Rodrigue (2024) has divided freight methods into six different main categories. These are air, truck, rail, maritime, inland/costal, and pipeline. Pipelines can only be used by transporting liquids (particularly oil) and gases. Each transport mode is distinguished by their own features and requirements. These technical, operational, and commercial features are illustrated in below figure. (Rodrigue, 2024, p. 127)

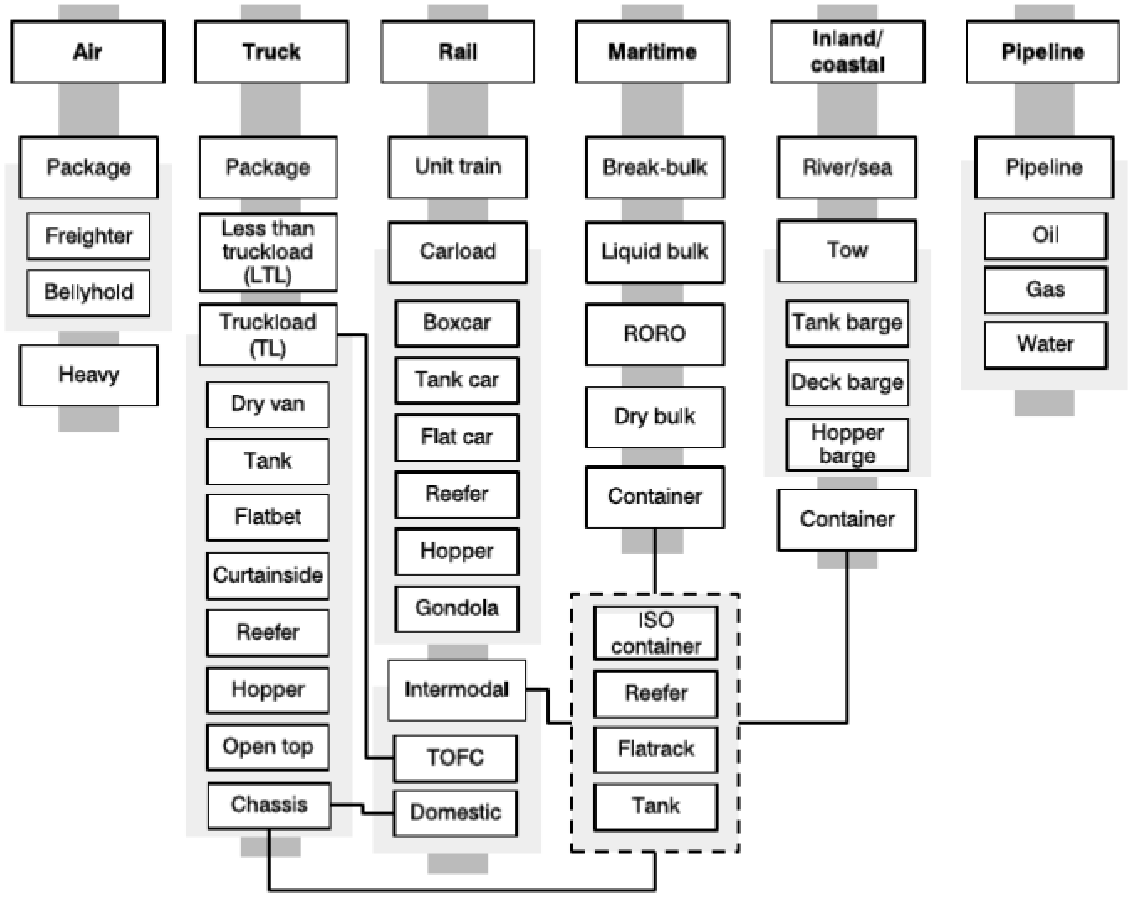

Figure 9. Different freight methods (Rodrigue, 2024, p.128)

When it comes to selecting transportation, there are many different factors that will affect the company trading goods. These factors can for instance be the measures of the goods, the destination country, the transportation time, rules and regulations, and environmental and safety considerations. (Eurostat, 2023a)

In figure 10, the share of extra-EU trade, measured in quantity, by different transport modes are being shown. In 2022, the maritime transportation accounts for 76 % of goods transported from EU and 74 % of goods transported to EU. Sea transportation has increased its share of the total quantity of goods being exported and imported from and to EU since 2002. The share of air transportation is very low when the trade is being measured in terms of quantity, not even 1 % when it comes to both EU exports and imports in 2022. (Eurostat, 2023a)

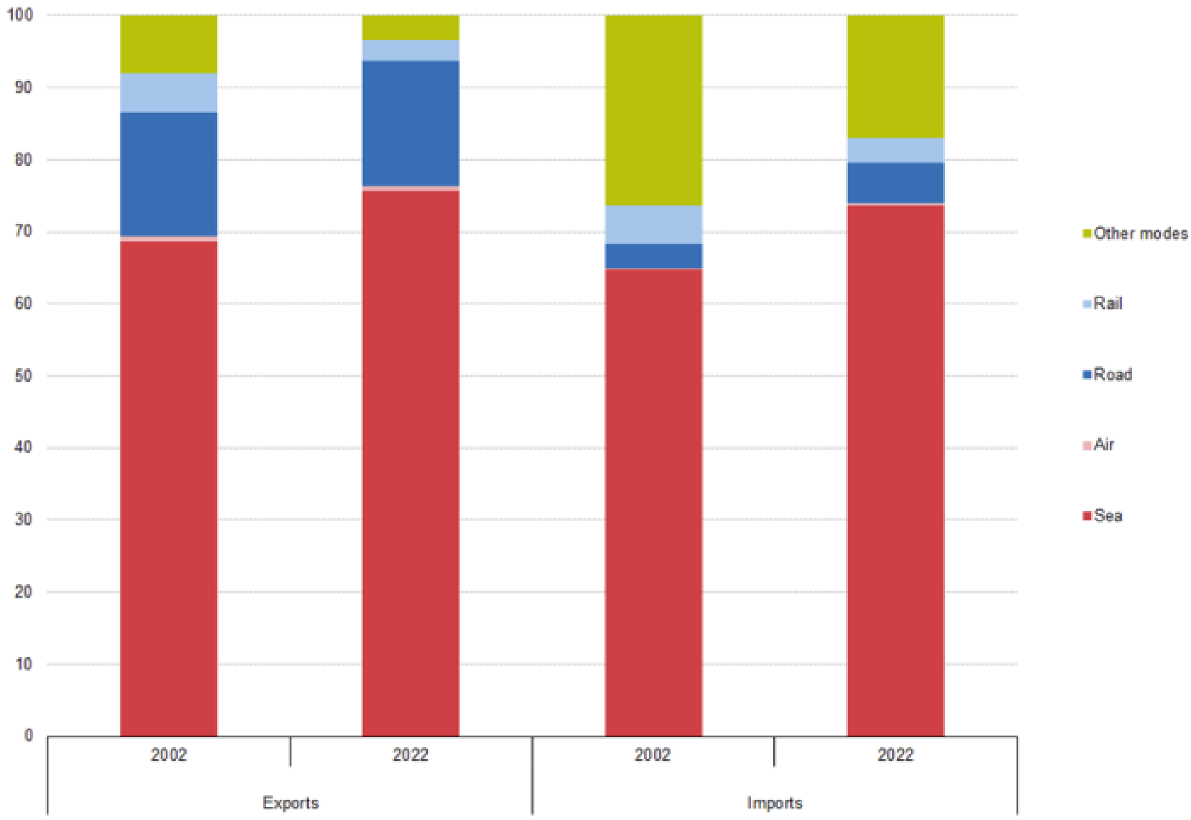

Figure 10. Goods traded between EU and the rest of the world measured in quantity by mode of transport 2002 versus 2022. (Eurostat, 2023a)

In figure 11, the share of extra-EU trade, measured in value, by different transport modes are being shown. The biggest differences in figure 11 compared to figure 10 can be seen in the air transportation and sea transportation. In 2022, the goods traded by air transportation between EU and the rest of the world was approximately 20 %. This gives an indication on how high the unit values of the goods are when air freight is selected as transportation mode. In 2022, the maritime transportation sector accounted for almost 52 % of the value of goods imported to the EU and 40 % of the value of goods exported from EU. Measured in quantity, this share was around 2/3 in both export and import. On the other hand, road transportation accounts for a bigger share measured in quantity instead of value. Both 2002 and 2022. (Eurostat, 2023a)

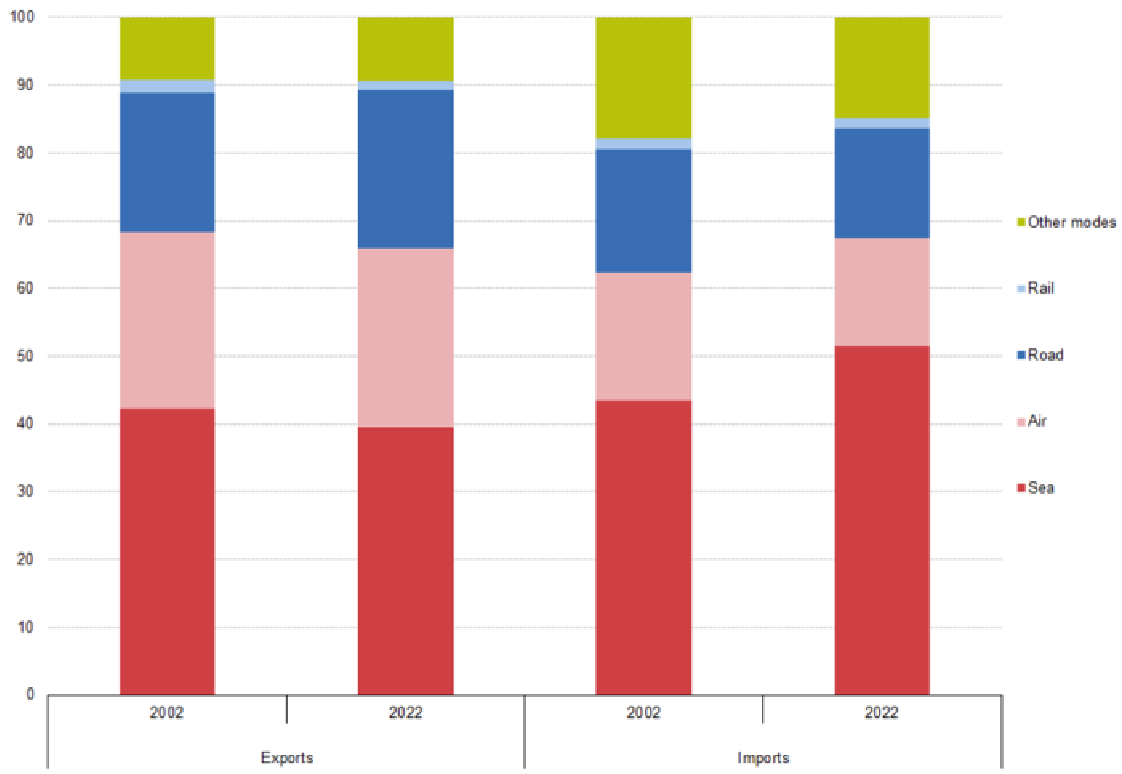

Figure 11. Goods traded between EU and the rest of the world measured in value by mode of transport 2002 versus 2022. (Eurostat, 2023a)

3.8.1 Road transportation

Road transportation requires a good infrastructure which leads to a large usage of land space. The maintenance cost for road transport is high, concerning both vehicles and infrastructures. Road transportation is mostly used by lighter industries where smaller volumes of freight need to be moved in an effective way. (Rodrigue, 2024, p. 132)

Transportation by truck is a flexible mode of transport, for almost all types of cargo. Packages, boxes, and pallets for urban freight distribution are usually transported in package trucks. Less-than-truckload (LTL) shipping is often used to transport goods for instance to a consolidation point from different suppliers. LTL shipments does not require a full truckload (FTL) trailer. FTL, also called truckload (TL) shipping means that one shipment requires the entire truck. (Rodrigue, 2024, p. 132)

When selecting the road vehicle for a transport, many factors need to be taken into consideration. These factors can for example be narrow roads, low bridges, product characteristics (size, weight, hazardous, liquid, frozen, live animals etc.), fuel consumption, and fuel type. (Rushton et al., 2014, p. 520)

The advantages of using road transportation are that it is a relatively fast transportation mode with no trans-shipment, as well as the low transportation costs which makes it very cost effective. It is also a flexible alternative with complete door-to-door services. The disadvantages of using road transportation are the limited loading capacities as well as the fact that it is affected by changing weather conditions and the traffic. (GWT, n.d.)

3.8.2 Rail transportation

Rail transportation, similar to road transportation, does require a lot of land space where networks of railways can be built. In Europe, many companies are operating by public owned monopolies while there’s oligopoly in North America (Rodrigue, 2024, p.135). Even if rail transportation is the most environmentally friendly mode of transport, the share of rail transportation compared to all other transport modes is significantly low (European Commission, n.d.-c).

The main advantages of using rail transportation are the large loading capacity as well as fast deliveries over longer distances. Rail transportation is also a very ecofriendly transportation mode. Most often, the transit times and schedules are reliable when using railroads. The main disadvantage of using rail transportation is the additional costs related to trans-shipments and lifting arrangements. (GWT, n.d.)

3.8.3 Maritime transportation

Two main physiography elements of the maritime transportation are oceans and rivers. Maritime routes are necessary for the existence of maritime transportation. Even if great improvements have been done to the safety and reliability of the maritime transportation during the years, the maritime transports are of course affected by weather phenomena, for instance forceful winds and currents. (Rodrigue, 2024, p. 140)

Maritime transportation is the most efficient option for transportation of larger amounts of freight for a longer distance that is not time sensitive (Rushton et al., 2014, p.26). Generally, maritime freight is used by two main markets: bulk cargo, and break-bulk cargo. Goods shipped as bulk cargo can either be dry or liquid and it often requires specific storage facilities or transshipments. One example is oil tankers. Bulk cargo has usually only one origin, destination, and customer. Break bulk cargo means cargo that has been packed in containers, boxes, or bags. Break bulk cargo has many different origins, destinations, and customers. (Rodrigue, 2024, pp. 142 – 143)

The global freight maritime shipping industry is divided into three different vessel types: Bulk carriers, general cargo and roll-on/roll-off (RORO) vessels. Bulk carriers are either liquid bulk vessels or dry bulk vessels and these are designed for specific freights. General cargo vessels are transporting non-bulk cargos. These are usually called container ships. Cars and trucks can drive onboard a RORO vessel with their freight. (Rodrigue, 2024, p. 143)

The advantages of using sea transportation are many. It is the most environmentally friendly transportation mode of all transportation modes. It is also very cost effective as well as it is suitable for many different kinds of goods. Especially for heavier shipments that need to be transported longer distances sea transportation is an economical option. The disadvantages of using sea transportation are the slow transportation times and the trans-shipment at seaports which both require extra time and add additional costs. (GWT, n.d.)

3.8.4 Air transportation

Air transport is usually considered when the freight is fragile, time-critical, or valuable and needs to be transported longer distances. In very urgent situations, or emergency situations, air transport is highly appreciated due to its fast delivery. In these situations, cost issues are less important. Transportation goods by air is only 2 % of the total weight of world trade yearly, but if measured by value, it is as much as 40 %. (Rodrigue, 2024, p. 151)

Air transportation has made it possible for certain perishable goods to be available 12 months a year in places where it otherwise would be only seasonally available. Perishable food is for instance fruits, vegetables, and fish. (Rushton et al., 2014, p. 469)

The advantages of using air transportation are its extremely fast delivery times (especially for longer distances), the high reliability, and the easy tracking and tracing systems. The disadvantages of using air transportation are that it is often very expensive and has a restricted loading capacity. Also in air transportation, trans-shipment is necessary. (GWT, n.d.)

3.9 Intermodular transports

When more than one freight method is in use for a transport, it is called an intermodular transportation. The intermodular transport chain includes shipping from an origin to a destination with two or more transport modes, typically road and air or road and sea. There are in general four activities that define the intermodular transport chain: composition, connection, interchange, and decomposition. (Rodrigue, 2024, p. 155). In figure 12 on page 39, the intermodal transport chain is illustrated.

Composition is the first step in the intermodular transport chain. Packaging, warehousing, and consolidating are all activities in the composition process. Composition is the process of consolidating goods at a terminal that provides some kind of intermodal connection between a regional distribution system and a domestic or international distribution system. Best case scenario is that many packages from different suppliers are being consolidated to a distribution centre so they can be shipped forward by maritime or rail transport which both are considered as high-capacity modes. Usually, the freight mode for the composition process is trucking due to its door-to-door services and flexibility. (Rodrigue, 2024, p. 155)

The **connection** process is the transfer between two or more terminals by a consolidated modal flow, for instance containership, freight train, or in some cases even fleets of trucks or air freight. This connection is between the domestic or international distribution systems. (Rodrigue, 2024, p. 155)

An **interchange** terminal is for instance a port or transshipment hub, and these are being used in both national and international distribution systems. The purpose of an interchange terminal is to allow a profitable continuity to the transport chain. (Rodrigue, 2024, p. 155)

Decomposition is the fourth and last step in the intermodal transport chain. This is the process when the freight will be split into its original pieces of packages and transferred to the local distribution system. This happens when the freight has arrived to a terminal close to its end destination. Decomposition is usually considered as the most difficult step in the transport chain. (Rodrigue, 2024, p. 155)

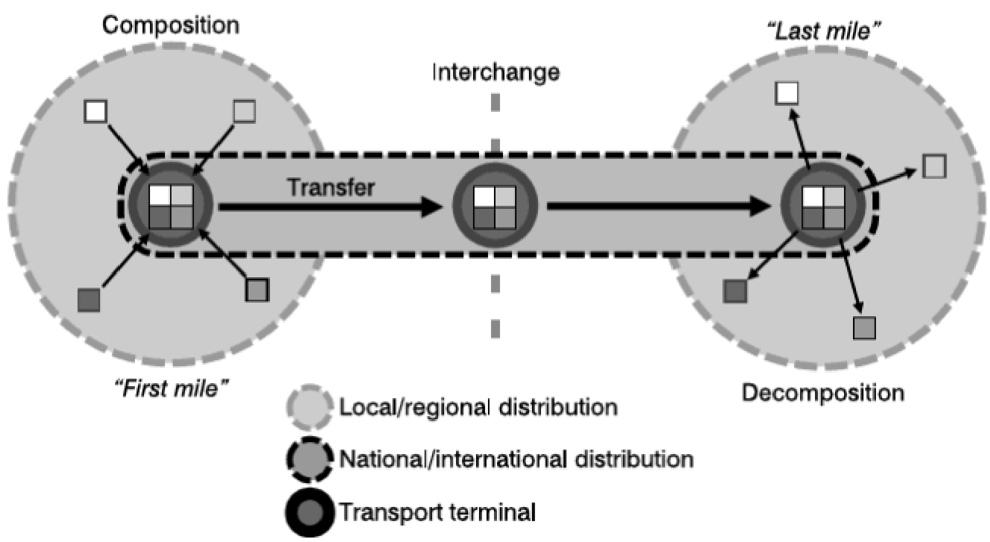

Figure 12. Intermodal transport chain. (Rodrigue, 2024, p.156)

3.10 Intermodal containers

Intermodal containers, also called ISO containers, are containers that have standardized measures and design in order to enable the use of this equipment all around the world. These containers are usually constructed of steel and have a rectangular shape. An intermodal container is designed for intermodal freight methods, which means that several transportation modes such as road, rail and sea transport. (Rushton et al., 2014, pp. 486 – 489)

There are different types of intermodal containers, the most common ones are listed below. Most commonly, the different containers are available in size 20 feet, 40 feet and 45 feet in length. The width dimensions are 8 feet for all containers and the height is 8 feet 6 inches. High cube containers are exceptions with a height of 9 feet 6 inches. (Rushton et al., 2014, pp. 486 – 489)

- **Dry containers** are the most commonly known shipping containers. Dry containers are used to ship dry cargo that is not temperature sensitive. (Freja, n.d.-a)
- **Open-top containers** are available for goods that need to be lifted in from the top, or goods that do not fit into a standard container (Rushton et al., 2014, p. 487).
- **High cube dry containers** are similar to the dry containers, but high cube dry containers are 30 cm higher. Light and voluminous cargo are typical for these types. (Freja, n.d.-c)
- **Flat-rack containers** are open on the long side of the container and has only sides on the short sides. Cargo with unique dimensions is typically transported in a flat rack container. (Freja, n.d.-b)
- **Tanktainers** have a steel frame that meet the ISO dimensions, but inside the frame is a tank container. A tanktainer allows liquids or powders to be transported with intermodal freight methods. (Rushton et al., 2014, p. 487)

- **Refrigerated containers** are used for goods that need to be kept cool while being transported. Dairy products, fruits, and meat are common items shipped in a refrigerated container. (Rushton et al., 2014, p. 488)

Different freight companies use different abbreviations for the different types of containers. In this thesis, DC, DV, and GP refer to the standard dry container while both HC and HQ refer to a high cube dry container. OH refers to an open-top container.

Figure 13. Dry containers (Freja, n.d.-a)

Figure 14. Flat-rack containers (Freja, n.d.-b)

4 Methodology

This research is a study conducted for Wärtsilä Finland Oy. In this chapter, the research methodology will be explained. For this study, a quantitative research method will be used, and the nature of the research is an empirical study. In the first section, the research question and the research strategy will be presented, followed by the second section, which presents the data collection and data analysis.

4.1 Research strategy

The purpose of this study is to study the differences in transportation costs, environmental impacts, and delivery time for Wärtsilä Catalyst Systems' shipments. These values vary based on the location of the supplier and/or the consolidation point and the location of the destination. Further, the purpose is also to study how much Wärtsilä Catalyst Systems can save when it comes to transportation, by choosing suppliers located in Europe for European projects and supplier located in Asia for Asian projects. The research question of this study is defined as following:

- "How much can Catalyst Systems reduce their transportation costs, environmental impacts, and delivery time?"

The research method chosen for this thesis is a quantitative research method. This study can also be called a descriptive case study as the research was done in a real-world context (Saunders et al., 2023). The quantitative research method was chosen because the data collected and analysed are expressed in numbers (statistical data) and the study population can be referred to as respondent (Hennink et al., 2020, p. 16). According to Hennink et al. (2020, p. 16) the research method chosen is a quantitative research method since the purpose of the research is to quantify a problem and to answer the question "how much?" and the analysis of the answers are statistical.

4.2 Data collection and analysis

In this research, quantitative data was collected and analyzed. This section provides an overview of how the data was collected and analyzed, while the results will be presented in chapter 5. Following programs have been used in the data collection and analysis phase:

1. **SAP** – the case company's enterprise resource planning system. In this program, shipments used in this research have been created with correct departure point and destination points. Other information such as estimated time of departure and transport mode was also added to the shipment. The information from the shipment can be transferred to Logpay with one click.
2. **Salesforce, Logpay** – The program that the case company is using when sending out request for quotations (RFQs) to different forwarding companies. The same way of working was also used in this research, and in total seven different forwarding companies received RFQs for this study.
3. **Internet** – Sea transport distances were calculated by using the website www.sea-distances.org and air transport distances were calculated using the website www.distance.to. Road transport distances have been estimated using both Google Maps and www.distance.to.
4. **NTM Calc Basic 4.0** – an environmental performance calculator that calculates the environmental impact (including CO_2 emissions) based on which parameters have been chosen (transport mode, route, vehicle, distance, and shipment weight). Additional parameters (fuel type, road type, euro class, load factor etc.) can not be adjusted in this basic version.
5. **Microsoft Excel** – all collected data was gathered in various Excel sheets. The tables presented in the result chapter have been created using Microsoft Excel.

5 Results

In this chapter, the results of the research will be presented. First, the results for the transport routes and cases for NOR reactor and mixing will be presented, followed by the results for NOR elements. The results of NOR aux, loose, and spares will be presented in chapter 5.3. Lastly, the results per project will be summarized.

As it was presented in chapter 4, RFQs were sent out to seven different forwarding companies. If a forwarding company would have provided a quotation for every route and case that was requested, it would be 50 quotations in total. Below is a table of the answering percent for each forwarding company. The names of the forwarding companies will not be revealed. Therefore, they are called forwarding company A, B, C, and so on. To forwarding company E, only RFQs related to the air freight route were sent, therefore their answering percent is also 100. The character “H” in the result tables stands for the results of the calculations done with the program NTM Calc Basic 4.0.

Table 2. Answering percent of the forwarding companies.

	RFQs	Quotations	Answering %
Forwarding company A	50	50	100
Forwarding company B	50	50	100
Forwarding company C	50	6	12
Forwarding company D	50	11	22
Forwarding company E	4	4	100
Forwarding company F	50	0	0
Forwarding company G	50	0	0

5.1 NOR reactor and mixing

To calculate the CO_2e for the different transport routes and cases, the distance between the departure points and destination points was ascertained. For the NOR reactor and mixing cases, there are two different departure points and three different destination points. When the distances are known, and the transport mode is decided, the emissions can be calculated. In table 3 and 4, both the distances and the total emissions are being presented. The road distances were calculated with Google Maps and the sea distances with www.sea-distances.org. The emissions were calculated by using the program NTM Calc Basic 4.0.

Table 3. Distances in kilometers for the transport routes for NOR reactor and mixing shipments.

Case	Kg	Departure point	Destination point	Road (km)	Sea (km)	Road (km)
1	14258	Maardu, Estonia	HDZH Shipbuilding	12	27637	98
2	26147	Maardu, Estonia	HDZH Shipbuilding	12	27637	98
3	51285	Maardu, Estonia	HDZH Shipbuilding	12	27637	98
1	14258	Maardu, Estonia	Hanwha Ocean Co., Ltd	12	21492	63
2	26147	Maardu, Estonia	Hanwha Ocean Co., Ltd	12	21492	63
3	51285	Maardu, Estonia	Hanwha Ocean Co., Ltd	12	21492	63
1	14258	Maardu, Estonia	Fincantieri S.p.A.	12	7578	5
2	26147	Maardu, Estonia	Fincantieri S.p.A.	12	7578	5
3	51285	Maardu, Estonia	Fincantieri S.p.A.	12	7578	5
1	14258	Maardu, Estonia	Fincantieri S.p.A.	2150	-	-
2	26147	Maardu, Estonia	Fincantieri S.p.A.	2150	-	-
3	51285	Maardu, Estonia	Fincantieri S.p.A.	2150	-	-
1	14258	Suzhou, China	HDZH Shipbuilding	107	-	-
2	26147	Suzhou, China	HDZH Shipbuilding	107	-	-
3	51285	Suzhou, China	HDZH Shipbuilding	107	-	-
1	14258	Suzhou, China	Hanwha Ocean Co., Ltd	194	911	63
2	26147	Suzhou, China	Hanwha Ocean Co., Ltd	194	911	63
3	51285	Suzhou, China	Hanwha Ocean Co., Ltd	194	911	63
1	14258	Suzhou, China	Fincantieri S.p.A.	194	26711	5
2	26147	Suzhou, China	Fincantieri S.p.A.	194	26711	5
3	51285	Suzhou, China	Fincantieri S.p.A.	194	26711	5

Table 4. Emissions (CO_2e) for the transport routes for NOR reactor and mixing shipments.

Case	Kg	Departure point	Destination point	Road (CO2e)	Sea (CO2e)	Road (CO2e)	TOTAL (CO2e)
1	14258	Maardu, Estonia	HDZH Shipbuilding	13,77	8815,06	115,47	**8944,30**
2	26147	Maardu, Estonia	HDZH Shipbuilding	25,57	16370,82	211,75	**16608,14**
3	51285	Maardu, Estonia	HDZH Shipbuilding	50,16	32111,99	415,11	**32577,26**
1	14258	Maardu, Estonia	Hanwha Ocean Co.,	13,77	6981,43	74,12	**7069,32**
2	26147	Maardu, Estonia	Hanwha Ocean Co.,	25,57	12802,90	137,20	**12965,67**
3	51285	Maardu, Estonia	Hanwha Ocean Co.,	50,16	25111,72	268,96	**25430,84**
1	14258	Maardu, Estonia	Fincantieri S.p.A.	13,77	2461,70	5,96	**2481,43**
2	26147	Maardu, Estonia	Fincantieri S.p.A.	25,57	4514,38	10,93	**4550,88**
3	51285	Maardu, Estonia	Fincantieri S.p.A.	50,16	8854,55	21,43	**8926,14**
1	14258	Maardu, Estonia	Fincantieri S.p.A.	2556,00	-	-	**2556,00**
2	26147	Maardu, Estonia	Fincantieri S.p.A.	4688,89	-	-	**4688,89**
3	51285	Maardu, Estonia	Fincantieri S.p.A.	9196,83	-	-	**9196,83**
1	14258	Suzhou, China	HDZH Shipbuilding	126,92	-	-	**126,92**
2	26147	Suzhou, China	HDZH Shipbuilding	232,75	-	-	**232,75**
3	51285	Suzhou, China	HDZH Shipbuilding	456,52	-	-	**456,52**
1	14258	Suzhou, China	Hanwha Ocean Co.,	230,87	295,98	74,12	**600,97**
2	26147	Suzhou, China	Hanwha Ocean Co.,	423,4	542,78	137,20	**1103,38**
3	51285	Suzhou, China	Hanwha Ocean Co.,	830,44	1064,62	268,96	**2164,02**
1	14258	Suzhou, China	Fincantieri S.p.A.	230,87	8676,17	5,96	**8913,00**
2	26147	Suzhou, China	Fincantieri S.p.A.	423,4	15911,77	10,93	**16346,10**
3	51285	Suzhou, China	Fincantieri S.p.A.	830,44	31209,51	21,43	**32061,38**

In tables 3 and 4, only departure point, and destination point are being mentioned. Below is a list with more detailed explanation of the transport routes in table 3 and 4. The first and third transport leg (from the supplier to the seaport and from the seaport to the destination point) is by road, while sea transport is applicable for the leg between the seaports. For the transport route within China, only road transport is applied and from Maardu to Fincantieri S.p.A. both road and sea transport routes are valid options.

- Maardu, Estonia - Port of Tallinn, Estonia - Port of Shanghai, China - HDZH Shipbuilding, Shanghai, China
- Maardu, Estonia - Port of Tallinn, Estonia - Busan Port, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea
- Maardu, Estonia - Port of Tallinn, Estonia - Port of Monfalcone, Italy - Fincantieri S.p.A, Monfalcone, Italy
- Maardu, Estonia - Fincantieri S.p.A, Monfalcone, Italy
- Suzhou, China - HDZH Shipbuilding, Shanghai, China

- Suzhou, China - Port of Shanghai, China - Busan Port, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea
- Suzhou, China - Port of Shanghai, China - Port of Monfalcone, Italy - Fincantieri S.p.A, Monfalcone, Italy

In the following map (figure 15), the sea routes for the NOR reactor and mixing cases are shown in a very simplified way in purple. The two red dots are the departure points (Maardu and Suzhou), and the three yellow dots are the destination points (Fincantieri S.p.A., Hanwha Ocean Co., Ltd, and HDZH Shipbuilding). The orange route is from Maardu to Fincantieri S.p.A. by road. The brown route is a sea route going through Suez Canal, but now in spring 2024 this is not an option due to the current situation in the world. As it is being illustrated on the map, the sea route via Suez Canal is shorter and therefore also faster than going around Cape of Good Hope in South Africa.

Figure 15. Transport routes for NOR reactor and mixing cases.

RFQs were sent out to six different forwarding companies for the cases (1, 2, and 3) for NOR reactor and mixing cases. Two forwarding companies provided quotations for all of the RFQs, while two forwarding companies provided quotations to only one respective two of the routes. Following are one summary of the quotations from Suzhou, China, and one summary of the quotations from Maardu, Estonia.

Table 5. Summary of quotations for NOR reactor and mixing from Suzhou, China.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	SEA (2 x 40 FR)	10207,00	314,15	2
		2	SEA (2 x 40 FR)	11165,00	576,1	2
		3	SEA (3 x 40 FR)	16612,00	1129,98	2
	B	1	SEA (2 x 40 FR OW OH)	8186,00	304,98	5
		2	SEA (2 x 40 FR OW OH)	13665,00	559,29	5
		3	SEA (3 x 40 FR OW OH + 1 x 20 DC)	17525,00	1096,98	5
HDZH Shipbuilding	A	1	ROAD (2 x FTL)	1495,00	233,82	1
		2	ROAD (2 x FTL)	1495,00	233,82	1
		3	ROAD (3 x FTL)	2485,00	841,04	1
	B	1	ROAD (1 x trailer)	715,00	100,93	2
		2	ROAD (2 x trailer)	2185,00	185,09	2
		3	ROAD (2 x trailer + 1 x FTL)	3450,00	363,04	2
	D	1	ROAD (1 x truck)	946,52	190,00	2
		2	ROAD (2 x truck)	2075,79	349,00	3
		3	ROAD (2 x truck)	2117,96	648,00	3
Fincantieri S.p.A.	A	1	SEA (2 x 40 FR)	30489,00	10166,23	39
		2	SEA (2 x 40 FR)	34976,00	18643,31	39
		3	SEA (3 x 40 FR)	54379,00	36567,18	39
	B	1	SEA (2 x 40 FR OW OH)	31960,00	1284,35	40
		2	SEA (2 x 40 FR OW OH)	34797,00	2355,30	40
		3	SEA (3 x 40 FR OW OH + 1 x 20 DC)	55067,00	4169,69	40

Table 6. Summary of quotations for NOR reactor and mixing from Maardu, Estonia.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	SEA (2 x 40 FR)	41875,00	9892,77	40-50
		2	SEA (2 x 40 FR)	43367,00	18141,83	40-50
		3	SEA (3 x 40 FR)	68543,00	35583,58	40-50
	B	1	SEA (2 x 40 FR OW OH)	15915,00	1413,58	59
		2	SEA (2 x 40 FR OW OH)	18557,00	2592,29	59
		3	SEA (3 x 40 FR OW OH + 1 x 20 DC)	28562,00	5084,53	59
	C	1	SEA (2 x 40 FR)	21000,00	-	50
		2	SEA (2 x 40 FR)	21000,00	-	50
		3	SEA (3 x 40 FR)	31500,00	-	50
HDZH Shipbuilding	A	1	SEA (2 x 40 FR)	39945,00	10175,31	50-60
		2	SEA (2 x 40 FR)	40557,00	18659,97	50-60
		3	SEA (3 x 40 FR)	65985,00	36599,87	50-60
	B	1	SEA (2 x 40 FR OW OH)	17035,00	1322,28	49
		2	SEA (2 x 40 FR OW OH)	17815,00	2433,21	49
		3	SEA (3 x 40 FR OW OH + 1 x 20 DC)	28664,00	4772,53	49
	C	1	SEA (2 x 40 FR)	21000,00	-	50
		2	SEA (2 x 40 FR)	21000,00	-	50
		3	SEA (3 x 40 FR)	31500,00	-	50
Fincantieri S.p.A.	A	1	ROAD (2 x FTL)	20445,00	4684,39	2-3
		2	ROAD (4 x FTL)	54945,00	8590,46	2-3
		3	ROAD (5 x FTL)	71556,00	16849,41	2-3
	B	1	SEA (2 x 40 FR OW OH)	19295,00	1083,68	40
		2	SEA (2 x 40 FR OW OH)	19295,00	1987,30	40
		3	SEA (3 x 40 FR OW OH + 1 x 20 DC)	32590,00	3897,89	40

The differences between departure point Suzhou and departure point Maardu will be visualized in the following charts. There're different charts for the three destinations, as well as different charts for the three measures; price, emissions, and transit time. In total, there are nine charts for NOR reactor and mixing cases. The blue piles in every chart is the data provided from a forwarding company, and the orange piles in the emission charts are the results from the calculations done with NTM Calc Basic 4.0. The numbers 1, 2, and 3, stands for the cases with their different size and weight where case 1 is the smallest and lightest one, and case 3 is the biggest and heaviest one. Case 2 size and weight is in between the other two cases.

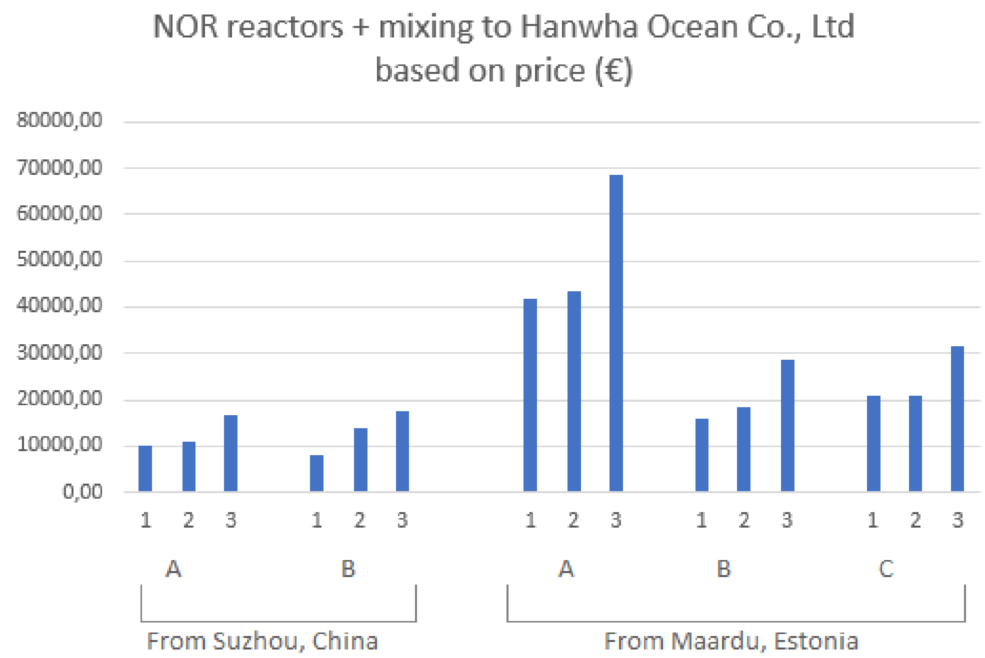

Figure 16. NOR reactors and mixing to Hanwha Ocean Co., Ltd based on price (€).

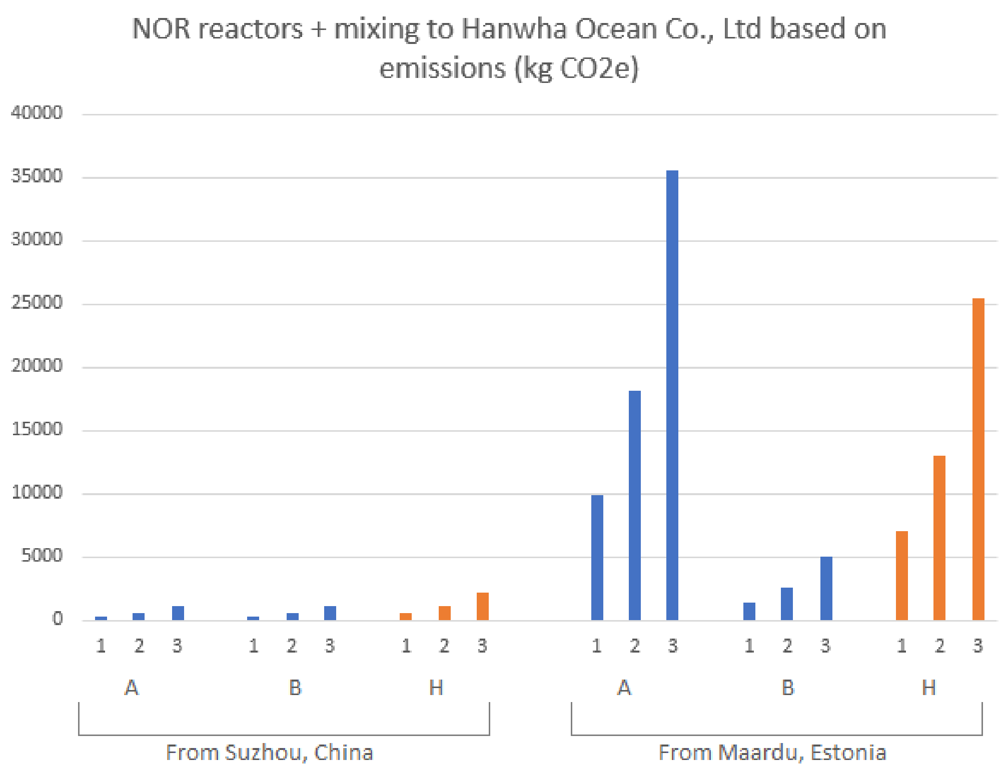

Figure 17. NOR reactors and mixing to Hanwha Ocean Co., Ltd based on emissions (kg CO_2e)

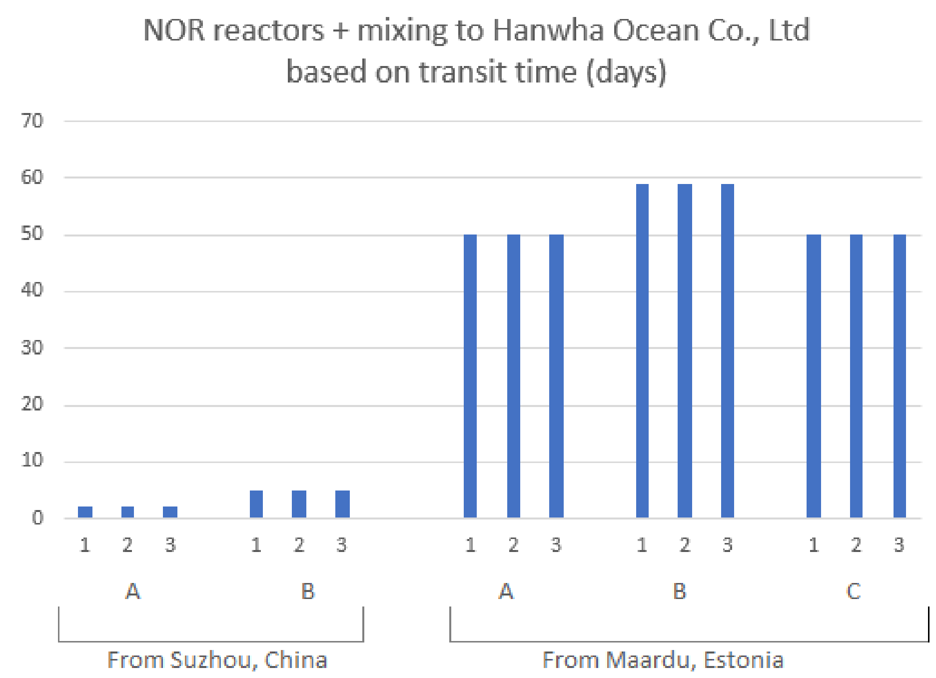

Figure 18. NOR reactors and mixing to Hanwha Ocean Co., Ltd based on transit time (days).

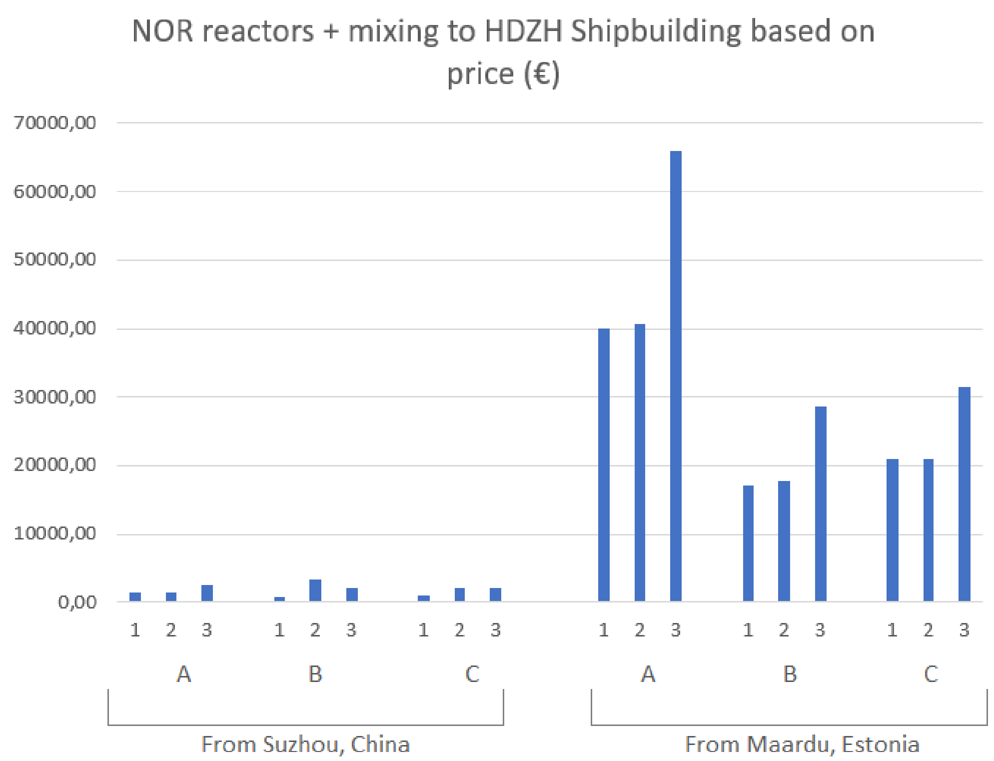

Figure 19. NOR reactors and mixing to HDZH Shipbuilding based on price (€).

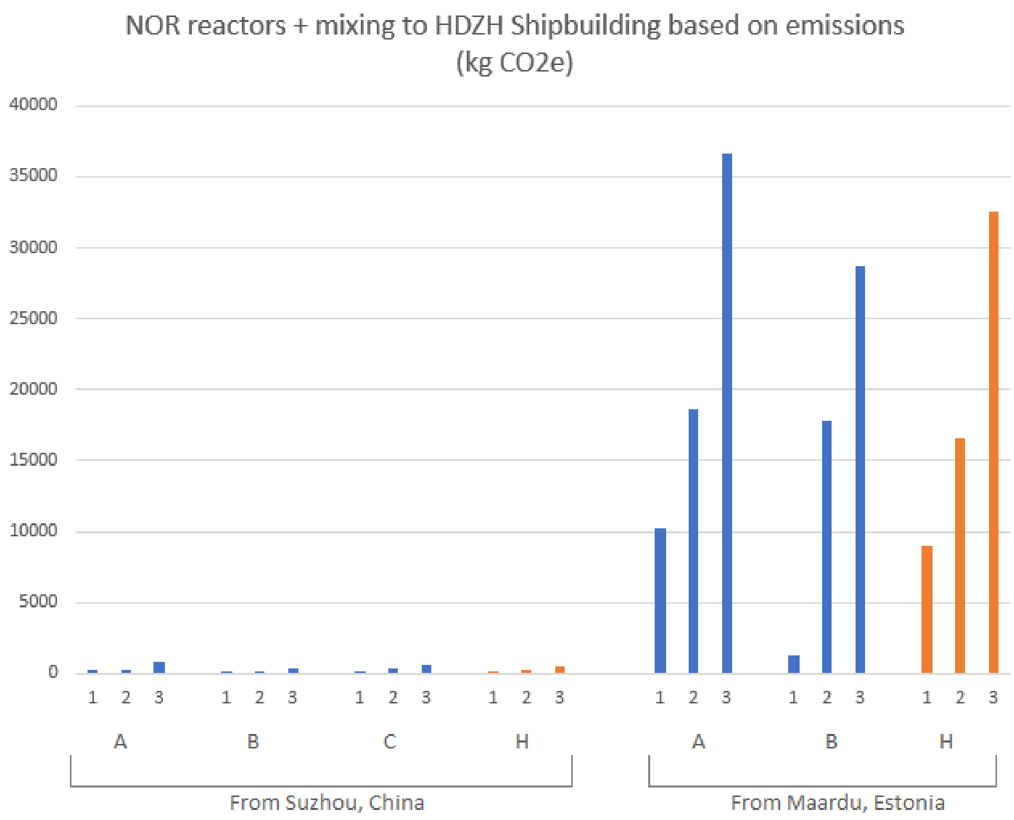

Figure 20. NOR reactors and mixing to HDZH Shipbuilding based on emissions (kg CO2e)

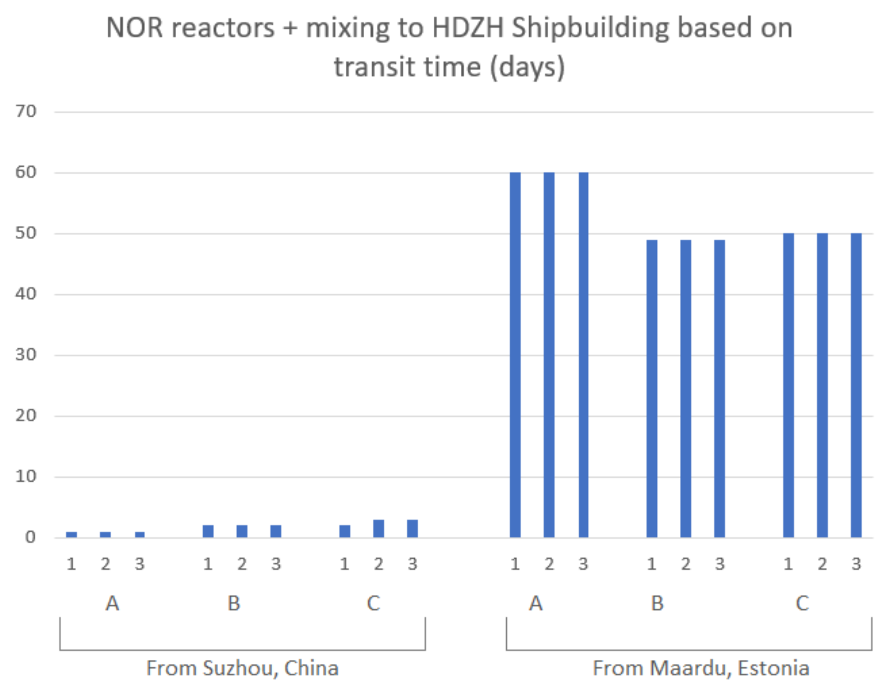

Figure 21. NOR reactors and mixing to HDZH Shipbuilding based on transit time (days).

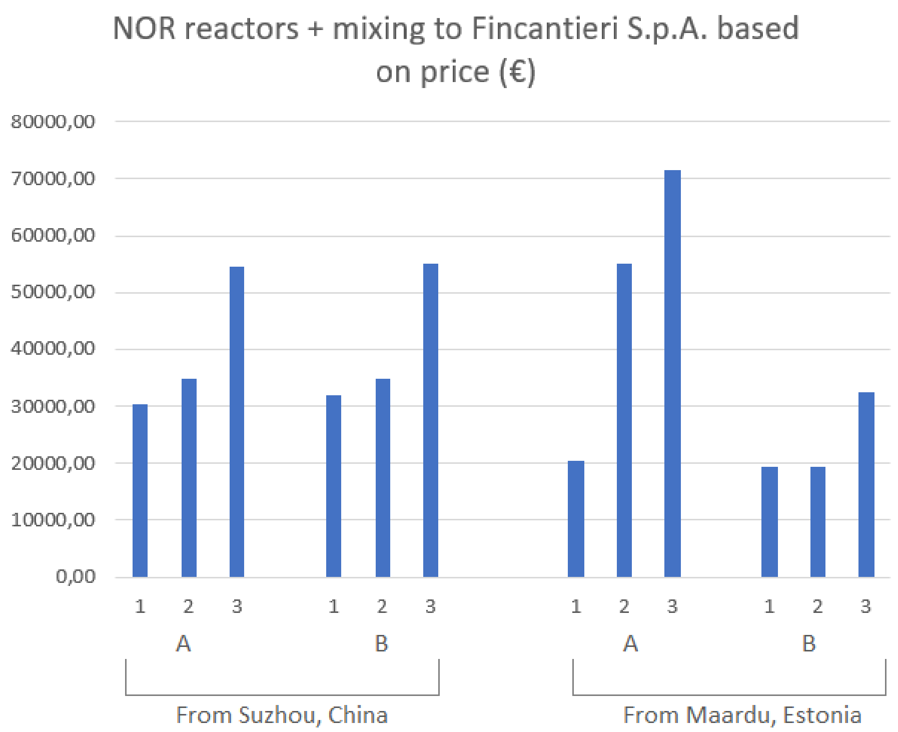

Figure 22. NOR reactors and mixing to Fincantieri S.p.A. based on price (€).

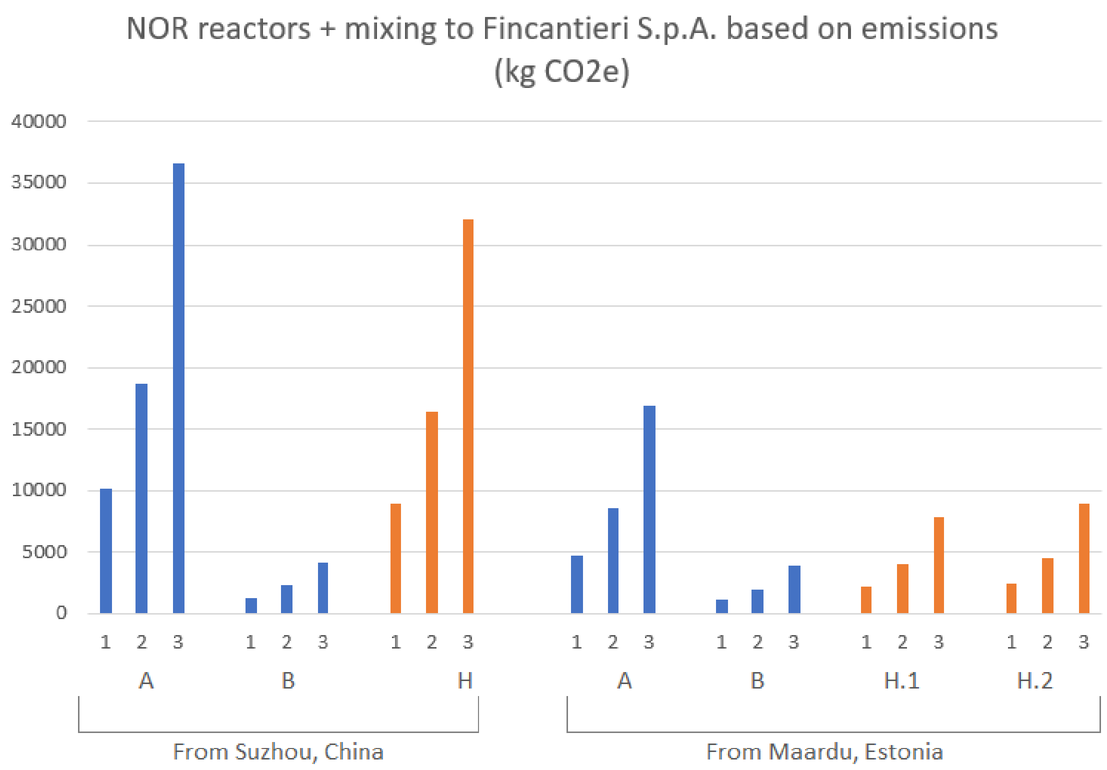

Figure 23. NOR reactors and mixing to Fincantieri S.p.A. based on emissions (kg CO_2e)

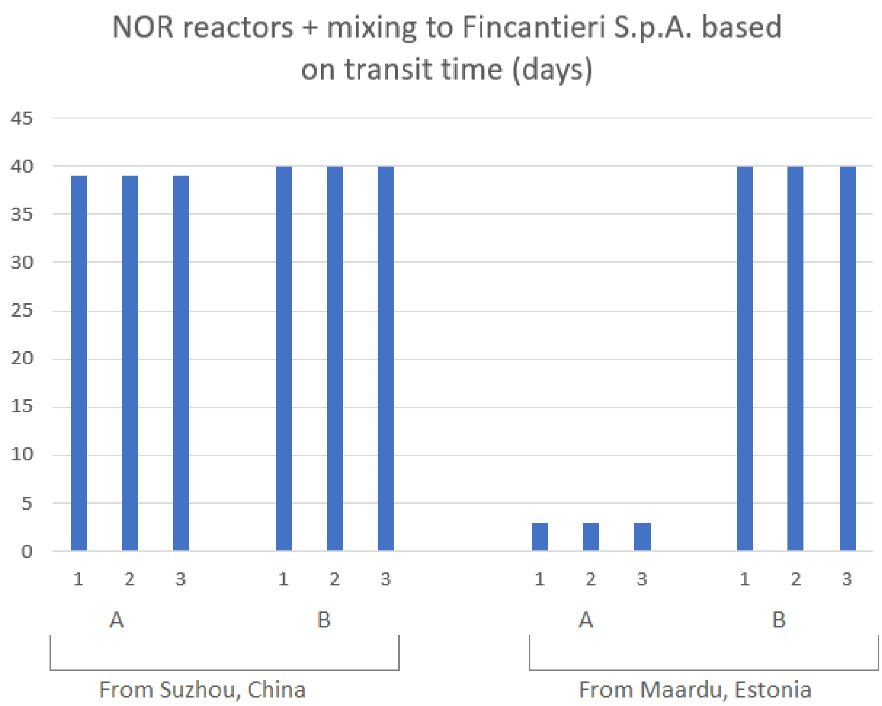

Figure 24. NOR reactors and mixing to Fincantieri S.p.A. based on transit time (days).

5.2 NOR elements

The same way of calculating CO_2e for the different transport routes and cases for NOR reactor and mixing has been used to calculate CO_2e for NOR elements. First, the distance between the departure points and destination points was ascertained. For the NOR element cases, there are two different departure points and three different destination points. When the distances are known, and the transport mode is decided, the emissions can be calculated. In tables 7 and 8, both the distances and the total emissions are being presented. The road distances were calculated with Google Maps and the sea distances with www.sea-distances.org. The emissions were calculated by using the program NTMCalc Basic 4.0.

Table 7. Distances in kilometers for the transport routes for NOR element shipments.

Case	Kg	Departure point	Destination point	Road (km)	Sea (km)	Road (km)
1	5856	Redwitz, Germany	HDZH Shipbuilding	496	26106	98
2	10550	Redwitz, Germany	HDZH Shipbuilding	496	26106	98
3	32821	Redwitz, Germany	HDZH Shipbuilding	496	26106	98
1	5856	Redwitz, Germany	Hanwha Ocean	496	26604	63
2	10550	Redwitz, Germany	Hanwha Ocean	496	26604	63
3	32821	Redwitz, Germany	Hanwha Ocean	496	26604	63
1	5856	Redwitz, Germany	Fincantieri S.p.A.	760	-	-
2	10550	Redwitz, Germany	Fincantieri S.p.A.	760	-	-
3	32821	Redwitz, Germany	Fincantieri S.p.A.	760	-	-
1	5856	Gyeongbuk, Korea	HDZH Shipbuilding	140	911	98
2	10550	Gyeongbuk, Korea	HDZH Shipbuilding	140	911	98
3	32821	Gyeongbuk, Korea	HDZH Shipbuilding	140	911	98
1	5856	Gyeongbuk, Korea	Hanwha Ocean	216	-	-
2	10550	Gyeongbuk, Korea	Hanwha Ocean	216	-	-
3	32821	Gyeongbuk, Korea	Hanwha Ocean	216	-	-
1	5856	Gyeongbuk, Korea	Fincantieri S.p.A.	140	27210	5
2	10550	Gyeongbuk, Korea	Fincantieri S.p.A.	140	27210	5
3	32821	Gyeongbuk, Korea	Fincantieri S.p.A.	140	27210	5

Table 8. Emissions (CO_2e) for the transport routes for NOR element shipments.

Case	Kg	Departure point	Destination point	Road (CO2e)	Sea (CO2e)	Road (CO2e)	TOTAL (CO2e)
1	5856	Redwitz, Germany	HDZH Shipbuilding	242,08	3482,87	47,42	**3772,37**
2	10550	Redwitz, Germany	HDZH Shipbuilding	436,12	6274,65	85,44	**6796,21**
3	32821	Redwitz, Germany	HDZH Shipbuilding	1356,77	19520,39	265,80	**21142,96**
1	5856	Redwitz, Germany	Hanwha Ocean	242,08	4689,88	30,73	**4962,69**
2	10550	Redwitz, Germany	Hanwha Ocean	436,12	8449,15	55,36	**8940,63**
3	32821	Redwitz, Germany	Hanwha Ocean	1356,77	26285,27	172,21	**27814,25**
1	5856	Redwitz, Germany	Fincantieri S.p.A.	371,14	-	-	**371,14**
2	10550	Redwitz, Germany	Fincantieri S.p.A.	668,63	-	-	**668,63**
3	32821	Redwitz, Germany	Fincantieri S.p.A.	2080,10	-	-	**2080,10**
1	5856	Gyeongbuk, Korea	HDZH Shipbuilding	68,39	160,63	47,42	**276,44**
2	10550	Gyeongbuk, Korea	HDZH Shipbuilding	123,30	289,38	85,44	**498,12**
3	32821	Gyeongbuk, Korea	HDZH Shipbuilding	383,31	900,26	265,80	**1549,37**
1	5856	Gyeongbuk, Korea	Hanwha Ocean	105,52	-	-	**105,52**
2	10550	Gyeongbuk, Korea	Hanwha Ocean	190,10	-	-	**190,10**
3	32821	Gyeongbuk, Korea	Hanwha Ocean	591,39	-	-	**591,39**
1	5856	Gyeongbuk, Korea	Fincantieri S.p.A.	68,39	3630,14	2,45	**3700,98**
2	10550	Gyeongbuk, Korea	Fincantieri S.p.A.	123,30	6539,95	4,41	**6667,66**
3	32821	Gyeongbuk, Korea	Fincantieri S.p.A.	383,31	20345,74	13,72	**20742,77**

In table 7 and 8, only departure point, and destination point are being mentioned. Below follows a list with more detailed explanation of the transport routes in table 7 and 8. The first and third transport leg (from the supplier to the seaport and from the seaport to the destination point) is by road, while sea transport is applicable for the leg between the seaports. Only road transport is applied for the transport route within South Korea, and for the transport route from Redwitz to Fincantieri S.p.A.

- Redwitz, Germany - Port of Hamburg, Germany - Port of Shanghai, China - Shanghai, China
- Redwitz, Germany - Port of Hamburg, Germany - Busan Port, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea
- Redwitz, Germany - Fincantieri S.p.A, Monfalcone, Italy
- Gyeongbuk, South Korea - Busan Port, South Korea - Port of Shanghai, China – Shanghai, China
- Gyeongbuk, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea
- Gyeongbuk, South Korea - Busan Port, South Korea - Port of Monfalcone, Italy - Fincantieri S.p.A, Monfalcone, Italy

In the following map (figure 25), the sea routes for the NOR element cases are shown in a very simplified way in purple. The two red dots are the departure points (Redwitz and Gyeongbuk), and the three yellow dots are the destination points (Fincantieri S.p.A., Hanwha Ocean Co., Ltd, and HDZH Shipbuilding). The orange route is from Redwitz to Fincantieri S.p.A. by road. The brown route is illustrated also on this map, but going via the Suez Canal is of course not an option for the transportation of NOR elements in spring 2024 either.

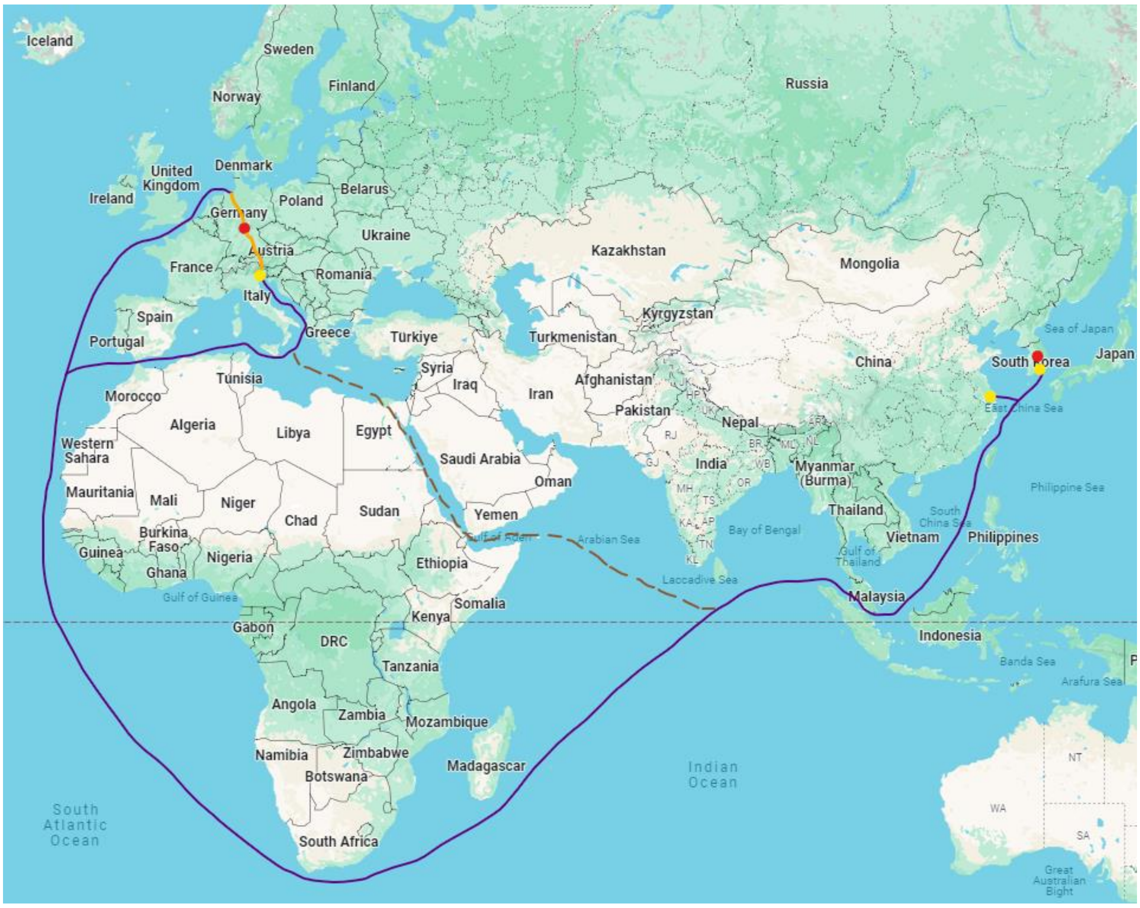

Figure 25. Transport routes for NOR element cases.

RFQs for NOR elements were sent out to six different forwarding companies for the cases (1, 2, and 3). Two forwarding companies provided quotations for all of the RFQs, while one forwarding company provided quotations to two of the routes. Following are one summary of the quotations from Suzhou, China, and one summary of the quotations from Maardu, Estonia.

Table 9. Summary of quotations for NOR elements from Gyeongbuk, South Korea.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	ROAD (1 x truck)	584,00	306,34	1-2
		2	ROAD (1 x truck)	1164,00	551,80	1-2
		3	ROAD (4 x truck)	3422,00	1716,64	1-2
	B	1	ROAD (1 x LTL)	320,00	158,32	1
		2	ROAD (1 x FTL)	450,00	285,23	1
		3	ROAD (3 x FTL)	1350,00	1049,57	1
	D	1	ROAD	314,00	-	1
		2	ROAD	699,00	-	1
		3	ROAD	2261,00	-	1
HDZH Shipbuilding	A	1	SEA (1 x 20 DV)	2185,00	131,16	1-2
		2	SEA (1 x 20 DV)	2695,00	236,29	1-2
		3	SEA (2 x 20 DV)	4805,00	735,10	1-2
	B	1	SEA (1 x 40 HC)	2065,00	124,98	2-4
		2	SEA (2 x 40 HC)	2065,00	176,87	2-4
		3	SEA (4 x 40 HC)	7735,00	650,82	2-4
	D	1	SEA (1 x 40 DC)	1515,00	-	1-3
		2	SEA (1 x 40 DC)	1745,00	-	1-3
		3	SEA (4 x 40 HQ)	6352,00	-	1-3
Fincantieri S.p.A.	A	1	SEA (1 x 20 DV)	5640,00	4136,76	50-60
		2	SEA (1 x 40 GP)	7189,00	7412,68	50-60
		3	SEA (2 x 40 GP)	13855,00	23185,24	50-60
	B	1	SEA (1 x 40 HC)	6255,00	671,64	71
		2	SEA (1 x 40 HC)	6255,00	1197,15	71
		3	SEA (4 x 40 HC)	24525,00	4405,19	71

Table 10. Summary of quotations for NOR elements from Redwitz, Germany.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	SEA (1 x 20 FT)	3267,00	3868,32	45-55
		2	SEA (1 x 20 HQ)	4007,00	6969,95	45-55
		3	SEA (2 x 40 HQ)	7970,00	21683,49	45-55
	B	1	SEA (1 x 40 HC)	4435,00	728,99	57
		2	SEA (1 x 40 HC)	4435,00	1278,35	57
		3	SEA (4 x 40 HC)	17215,00	4703,97	57
HDZH Shipbuilding	A	1	SEA (1 x 20 FT)	3339,00	3984,86	50-60
		2	SEA (1 x 20 HQ)	4085,00	7179,02	50-60
		3	SEA (2 x 40 HQ)	8194,00	22333,89	50-60
	B	1	SEA (1 x 40 HC)	3590,00	673,42	44
		2	SEA (1 x 40 HC)	3590,00	1208,19	44
		3	SEA (4 x 40 HC)	13895,00	4445,80	44
Fincantieri S.p.A.	A	1	ROAD (1 x LTL: 3,5 loading meters)	972,00	392,30	2
		2	ROAD (1 x LTL: 6,5 loading meters)	1195,00	706,76	2
		3	ROAD (2 x FTL)	1583,00	2198,72	2
	B	1	ROAD (1 x LTL)	980,00	244,75	7-9
		2	ROAD (1 x FTL)	1650,00	440,93	7-9
		3	ROAD (3 x FTL)	4950,00	1622,48	7-9

The differences between departure point Gyeongbuk and departure point Redwitz will be visualized in the following charts. There're different charts for the three destinations, as well as different charts for the three measures; price, emissions, and delivery time. In total, there are nine charts for elements cases. The blue piles in every chart is the data provided from a forwarding company, and the orange piles in the emission charts are the results from the calculations done with NTM Calc Basic 4.0. The numbers 1, 2, and 3, stands for the cases with their different size and weight where case 1 is the smallest and lightest one, and case 3 is the biggest and heaviest one. Case 2 size and weight is in between the other two cases.

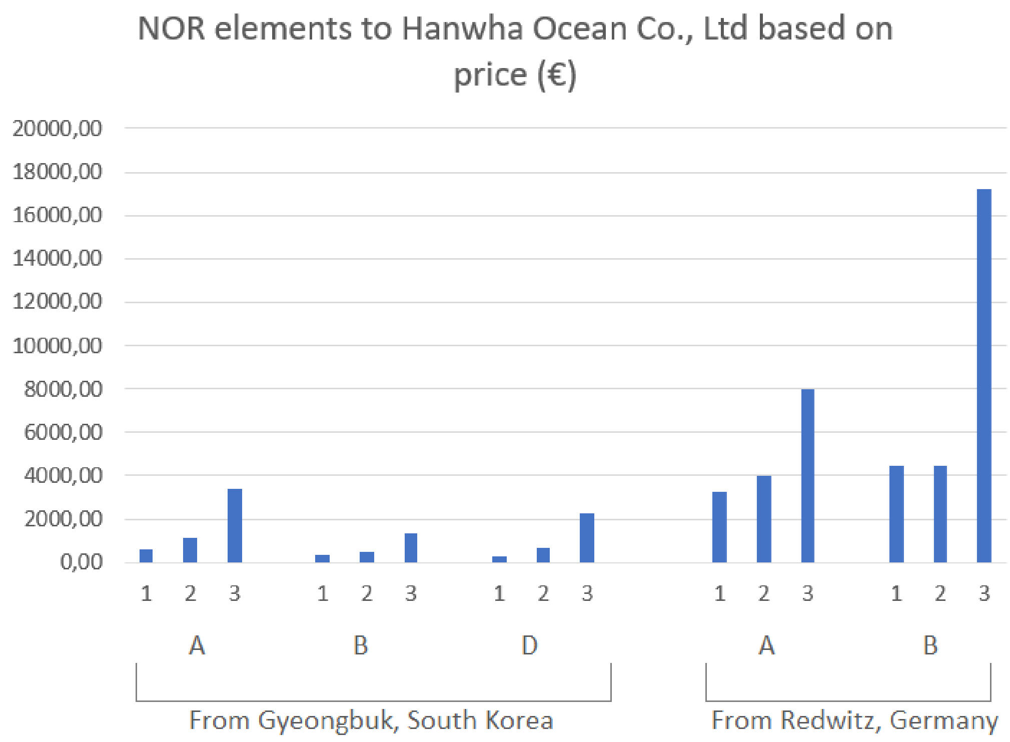

Figure 26. NOR elements to Hanwha Ocean Co., Ltd based on price (€).

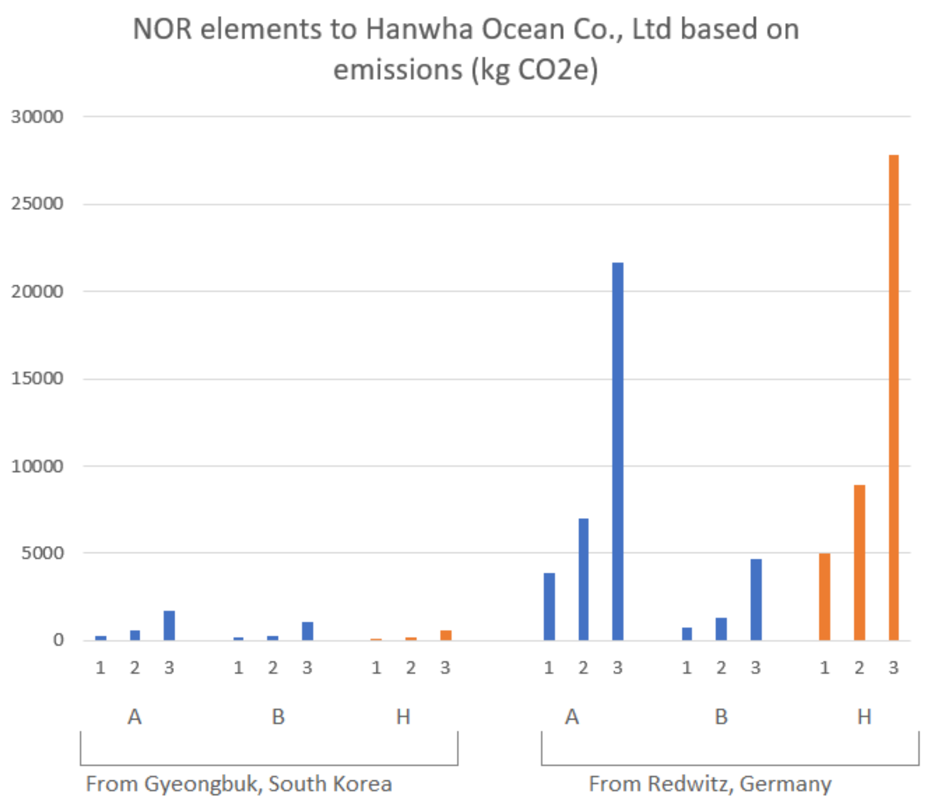

Figure 27. NOR elements to Hanwha Ocean Co., Ltd based on emissions (kg CO2e).

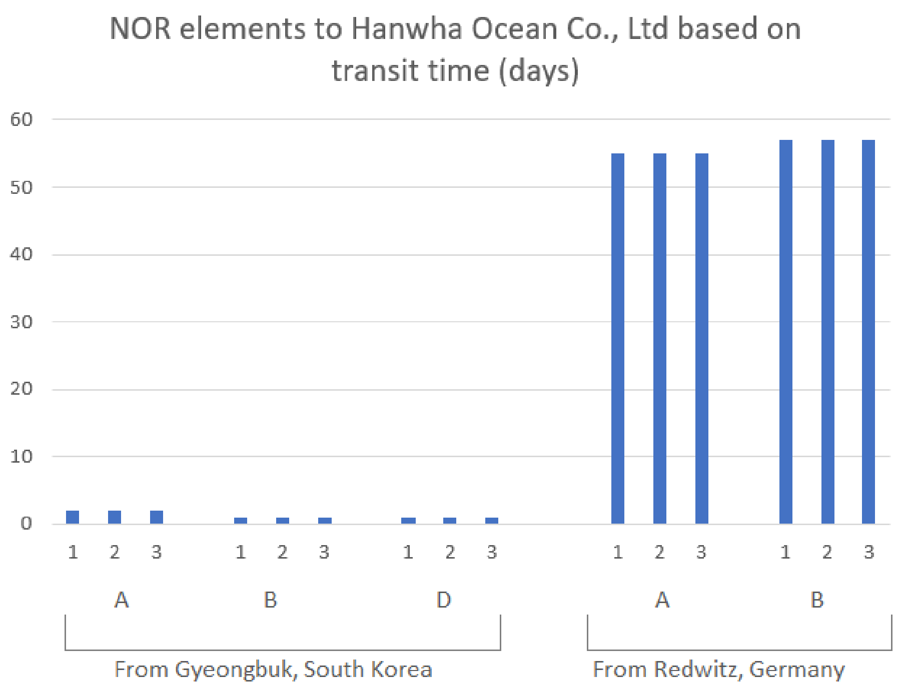

Figure 28. NOR elements to Hanwha Ocean Co., Ltd based on emissions (kg CO2e).

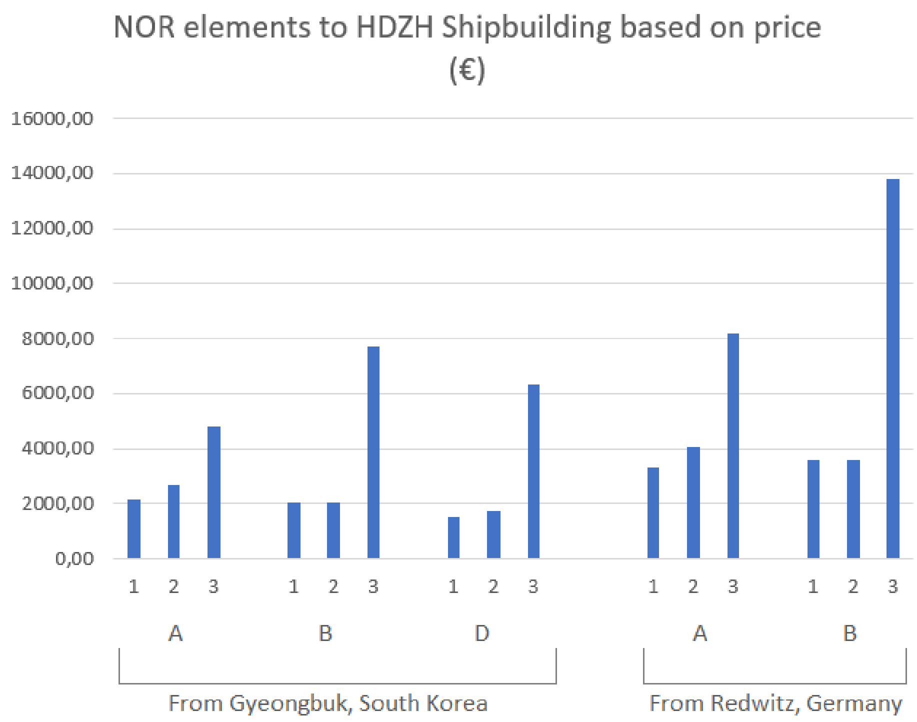

Figure 29. NOR elements to HDZH Shipbuilding based on price (€).

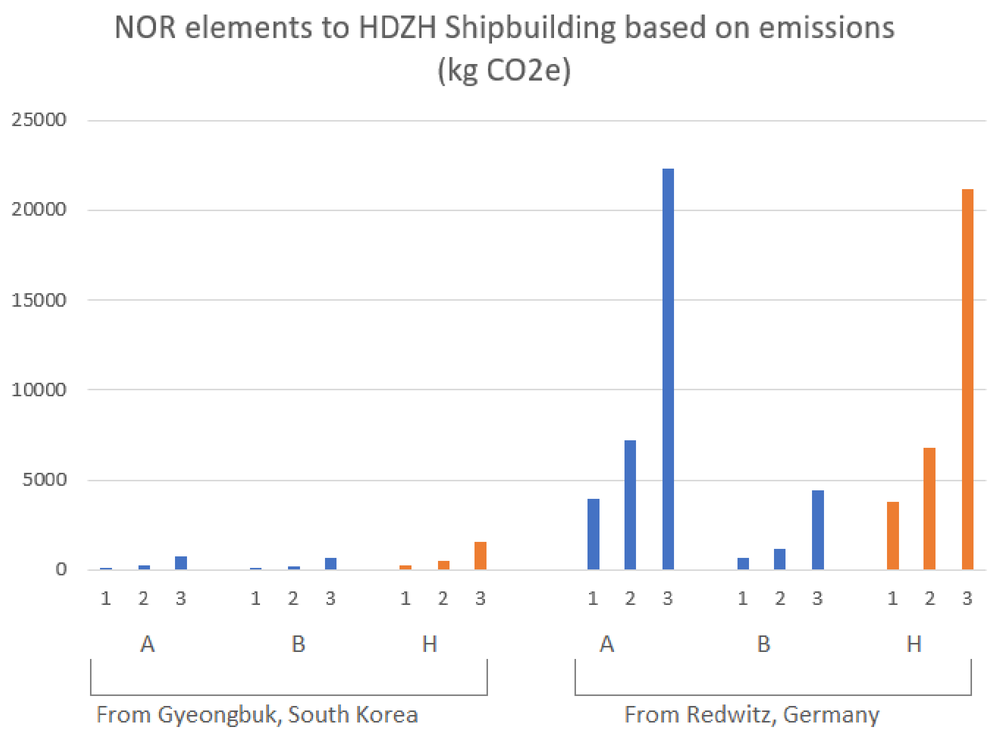

Figure 30. NOR elements to HDZH Shipbuilding based on emissions (kg CO2e).

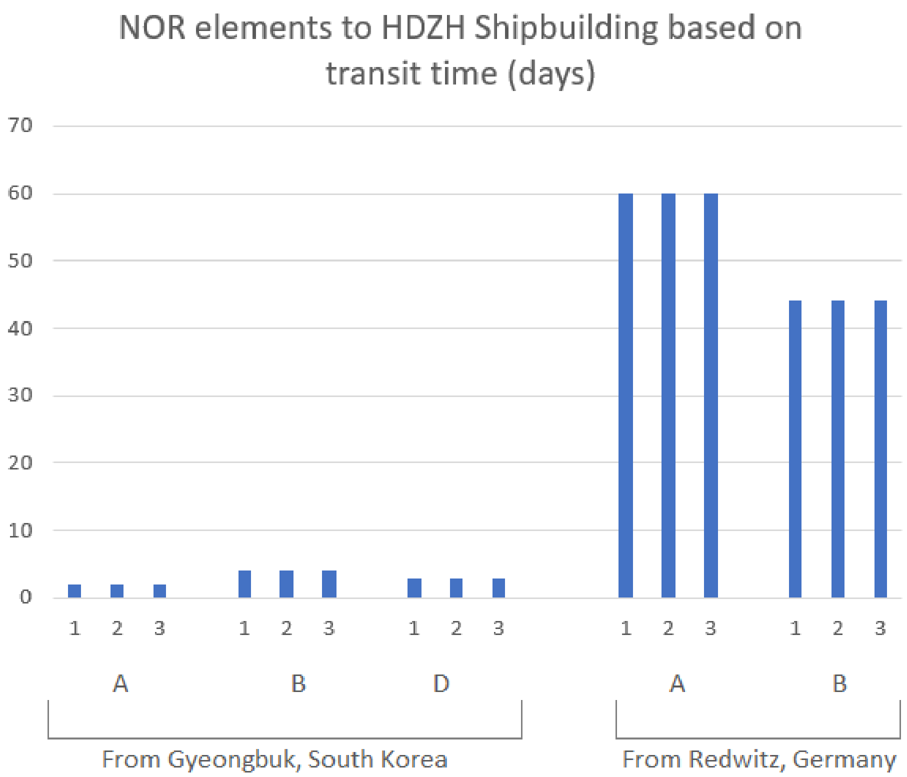

Figure 31. NOR elements to HDZH Shipbuilding based on transit time (days).

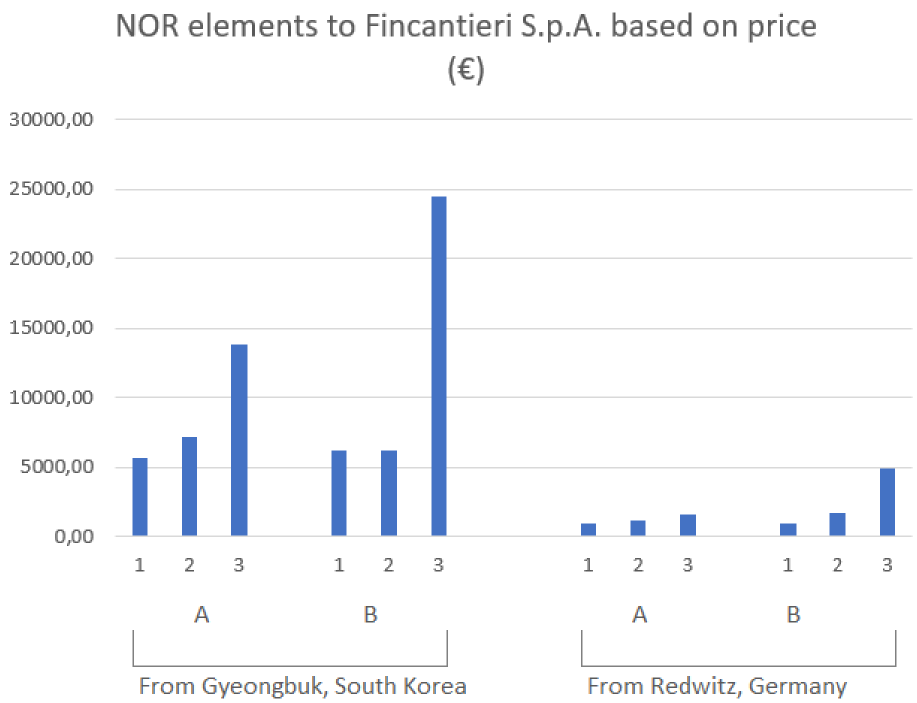

Figure 32. NOR elements to Fincantieri S.p.A. based on price (€).

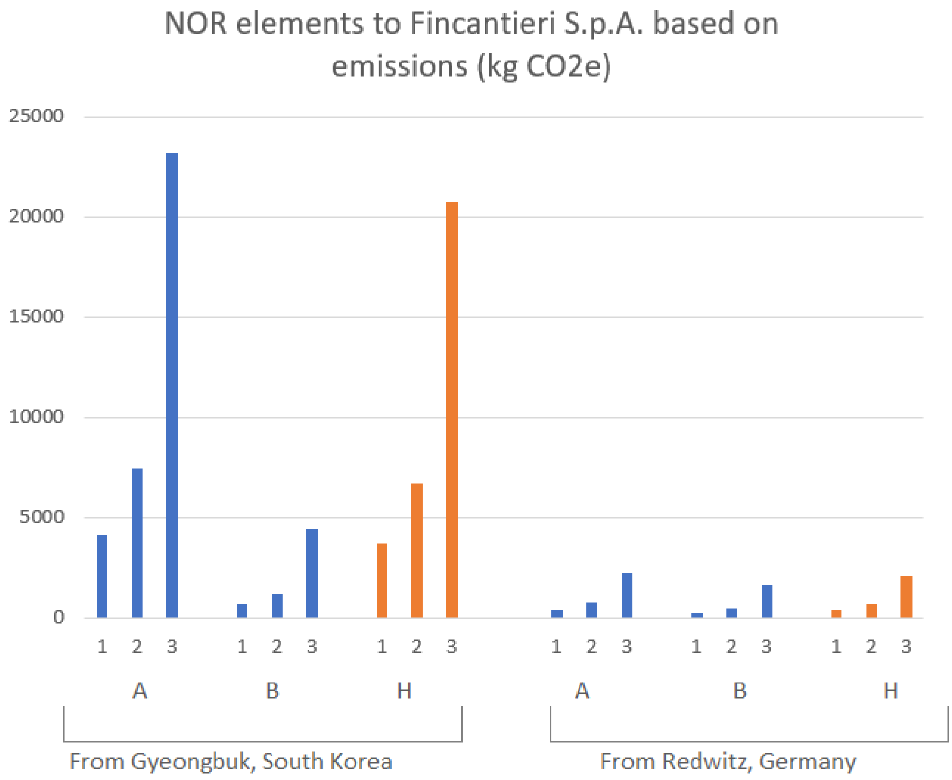

Figure 33. NOR elements to Fincantieri S.p.A. based on emissions (kg CO_2e).

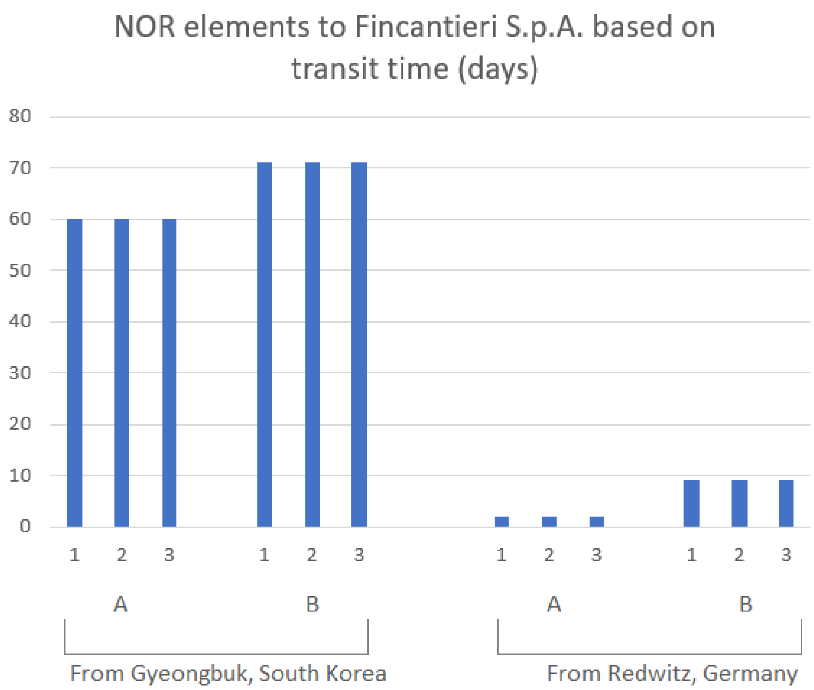

Figure 34. NOR elements to Fincantieri S.p.A. based on transit time (days).

5.3 NOR aux, loose, and spares

Lastly, the prices, emissions, and delivery time for NOR aux, loose, and spares cases will be presented. NOR aux, loose, and spares cases have three different departure points due to air freight being an option in some situations as well. The departure point for air freight is Vaasa, Finland. In tables 11 – 14, both the distances and the total emissions are being presented. The road distances were calculated with Google Maps and the sea distances with www.sea-distances.org. The air distances and the emissions were calculated by using the program NTM Calc Basic 4.0.

Table 11. Distances in kilometers for the transport routes for NOR aux, loose, and spares shipments.

Case	Kg	Departure point	Destination point	Road (km)	Sea (km)	Road (km)
1	1340	Mäntyluoto, Finland	HDZH Shipbuilding	-	27708	98
3	3082	Mäntyluoto, Finland	HDZH Shipbuilding	-	27708	98
1	1340	Mäntyluoto, Finland	Hanwha Ocean Co., Ltd	-	28206	63
3	3082	Mäntyluoto, Finland	Hanwha Ocean Co., Ltd	-	28206	63
1	1340	Mäntyluoto, Finland	Fincantieri S.p.A.	-	7649	5
3	3082	Mäntyluoto, Finland	Fincantieri S.p.A.	-	7649	5
1	1340	Suzhou, China	HDZH Shipbuilding	128	-	-
3	3082	Suzhou, China	HDZH Shipbuilding	128	-	-
1	1340	Suzhou, China	Hanwha Ocean Co., Ltd	211	911	63
3	3082	Suzhou, China	Hanwha Ocean Co., Ltd	211	911	63

Table 12. Emissions (CO_2e) for the transport routes for NOR aux, loose, and spares shipments.

Case	Kg	Departure point	Destination point	Road (CO2e)	Sea (CO2e)	Road (CO2e)	TOTAL (CO2e)
1	1340	Mäntyluoto, Finland	HDZH Shipbuilding	-	1117,7	10,85	**1128,54**
3	3082	Mäntyluoto, Finland	HDZH Shipbuilding	-	2570,7	24,96	**2595,64**
1	1340	Mäntyluoto, Finland	Hanwha Ocean Co., Ltd	-	861,08	7,03	**868,11**
3	3082	Mäntyluoto, Finland	Hanwha Ocean Co., Ltd	-	1980,5	16,17	**1996,66**
1	1340	Mäntyluoto, Finland	Fincantieri S.p.A.	-	233,50	0,56	**234,06**
3	3082	Mäntyluoto, Finland	Fincantieri S.p.A.	-	537,06	1,29	**538,35**
1	1340	Suzhou, China	HDZH Shipbuilding	14,80	-	-	**14,80**
3	3082	Suzhou, China	HDZH Shipbuilding	32,97	-	-	**32,97**
1	1340	Suzhou, China	Hanwha Ocean Co., Ltd	23,59	36,76	7,03	**67,38**
3	3082	Suzhou, China	Hanwha Ocean Co., Ltd	54,26	84,54	16,17	**154,97**

Table 13. Distances in kilometers for the air transport routes for NOR aux, loose, and spares shipments.

Case	Kg	Departure point	Destination point	Road (km)	Air (km)	Road (km)
1	1340	Vaasa, Finland	HDZH Shipbuilding	417	7561	36
3	3082	Vaasa, Finland	HDZH Shipbuilding	417	7561	36
1	1340	Vaasa, Finland	Hanwha Ocean Co., Ltd	417	7197	437
3	3082	Vaasa, Finland	Hanwha Ocean Co., Ltd	417	7197	437

Table 14. Emissions (CO_2e) for the air transport routes for NOR aux, loose, and spares shipments.

Case	Kg	Departure point	Destination point	Road (CO2e)	Air (CO2e)	Road (CO2e)	TOTAL (CO2e)
1	1340	Vaasa, Finland	HDZH Shipbuilding	46,61	8060,7	3,99	**8111,33**
3	3082	Vaasa, Finland	HDZH Shipbuilding	107,20	18540	9,18	**18656,06**
1	1340	Vaasa, Finland	Hanwha Ocean Co., Ltd	46,61	7688,2	48,85	**7783,70**
3	3082	Vaasa, Finland	Hanwha Ocean Co., Ltd	107,20	17683	112,40	**17902,54**

Below is a list with more detailed explanation of the transport routes in tables 11 – 14. The first and third transport leg (from the supplier to the seaport/airport and from the seaport/airport to the destination point) is by road, while sea transport is applicable for the leg between the seaports and air freight is applicable for the leg between the airports. The sea route and air route are calculated as direct routes, but in reality, there will be stops on the way depending on the chosen forwarding company's schedule and route. For the transportation of NOR aux, loose, and spares within China, only road transportation is applicable.

- Port of Pori, Finland - Port of Shanghai - HDZH Shipbuilding, Shanghai, China
- Port of Pori, Finland - Busan Port, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea
- Port of Pori, Finland - Port of Monfalcone, Italy - Fincantieri S.p.A, Monfalcone, Italy
- Suzhou, China - HDZH Shipbuilding, Shanghai, China
- Suzhou, China - Port of Shanghai, China - Busan Port, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea

- Vaasa, Finland - Helsinki-Vantaa Airport, Finland - Shanghai Airport, China - HDZH Shipbuilding, Shanghai, China
- Vaasa, Finland - Helsinki-Vantaa Airport, Finland - Seoul Airport, South Korea - Hanwha Ocean Co., Ltd, Geoje-Si, South Korea

In the following map (figure 35), the sea, road, and air routes for the NOR aux, loose, and spares cases are shown in a very simplified way in purple (sea), orange (road), and green (air). The three red dots are the departure points (Vaasa, Pori, and Suzhou), and the three yellow dots are the destination points (Fincantieri S.p.A., Hanwha Ocean Co., Ltd, and HDZH Shipbuilding). The brown route is illustrated on the map, but it is neither an option for the transportation of NOR aux, loose, and spares in spring 2024 due to the current situation in the world.

Figure 35. Transport routes for NOR aux, loose, and spares cases.

RFQs were sent out to six different forwarding companies for the cases (1, 2, and 3) for NOR aux, loose, and spares with departure points Olmar, Finland and Suzhou, China. Forwarding company A and B did send a quotation to all routes and cases, while forwarding company D only did send a quotation to one of the routes. RFQs for air freight from Vaasa to China and South Korea was sent out to three different forwarding companies, and all om them sent quotation to all routes.

Following are one summary of the quotations from Suzhou, China, one summary of the quotations from Pori, Finland, and one summary of the quotations from Vaasa, Finland.

Table 15. Summary of quotations for NOR aux, loose, and spares from Suzhou, China.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	SEA (1 x 20 DV)	2125,00	868,53	1-2
		3	SEA (1 x 20 DV)	2125,00	868,53	1-2
	B	1	SEA (1 x 20 DC)	1925,00	42,38	5
		3	SEA (1 x 40 DC)	2673,00	92,23	5
HDZH Shipbuilding	A	1	ROAD (1 x LTL)	320,00	23,53	1-2
		3	ROAD (1 x FTL)	430,00	51,22	1-2
	B	1	ROAD (1 x LTL)	350,00	19,63	1
		3	ROAD (1 x LTL)	512,00	42,73	1
	D	1	ROAD (1 x FTL)	500,00	19,00	1
		3	ROAD (1 x FTL)	715,00	42,00	1

Table 16. Summary of quotations for NOR aux, loose, and spares from Pori, Finland.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	SEA (1 x 20 DV)	2650,00	1025,78	50-60
		3	SEA (1 x 20 DV)	2770,00	2232,41	50-60
	B	1	SEA (1 x 20 DC)	2295,00	154,46	47
		3	SEA (1 x 20 DC)	2295,00	331,80	47
HDZH Shipbuilding	A	1	SEA (1 x 20 DV)	3207,00	995,41	50-60
		3	SEA (1 x 20 DV)	3331,00	2166,31	50-60
	B	1	SEA (1 x 20 DC)	2385,00	140,13	46
		3	SEA (1 x 20 DC)	2385,00	304,98	46
Fincantieri S.p.A.	A	1	Truck (1 x LTL)	1528,00	376,35	2-3
		3	Truck (1 x FTL)	2234,00	819,05	2-3
	B	1	SEA (1 x 20 DC)	2870,00	116,78	47
		3	SEA (1 x 20 DC)	2870,00	254,17	47

Table 17. Summary of quotations for NOR aux, loose, and spares from Vaasa, Finland by air.

DESTINATION POINT	FORWARDING COMPANY	CASE	MODE OF TRANSPORT	PRICE (€)	EMISSIONS (kg CO2e)	TRANSIT TIME (days)
Hanwha Ocean Co., Ltd	A	1	Air	4285,00	8644,30	1-2
		3	Air	7088,00	18812,66	1-2
	B	1	Air	3258,00	8768,93	3-4
		3	Air	5483,00	17840,64	3-4
	E	1	Air	3466,00	7906,28	3-4
		3	Air	6186,00	17206,49	3-4
HDZH Shipbuilding	A	1	Air	3682,00	8690,19	1-2
		3	Air	3517,00	18912,52	1-2
	B	1	Air	3074,00	8190,14	3-5
		3	Air	5248,00	17886,62	3-5
	E	1	Air	3193,00	10922,23	5-7
		3	Air	6304,00	23770,14	5-7

The differences between departure points Pori, Suzhou, and Vaasa will be visualized in the following charts. There're different charts for the three destinations, as well as different charts for the three measures; price, emissions, and delivery time. In total, there are nine charts for NOR aux, loose, and spares cases. The blue piles in every chart is the data provided from a forwarding company, and the orange piles in the emission charts are the results from the calculations done with NTM Calc Basic 4.0. For destination point Fincantieri S.p.A, only freight options from Pori, Finland are being investigated. This because the aux, loose, and spares units for all European projects are being manufactured in Finland and China is at least not an alternative today. The numbers 1, and 3, stands for the cases with their different size and weight where case 1 is the smaller and lightest one, and case 3 is the bigger and heavier one. As written earlier, case 2 is excluded from NOR aux, loose, and spares because the weights and dimensions of that case were almost identical to case 1.

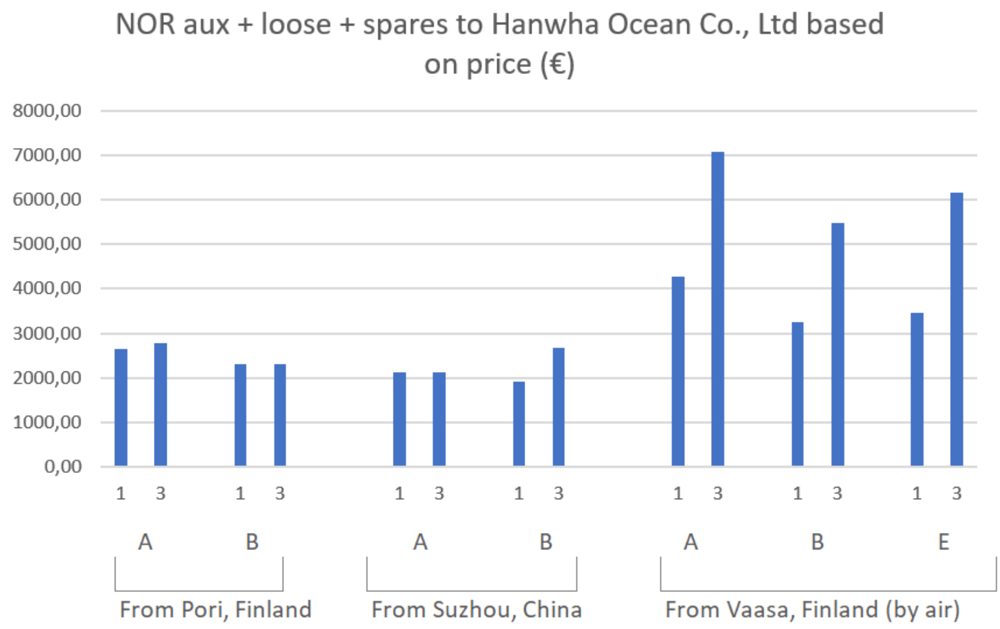

Figure 36. NOR aux, loose, and spares to Hanwha Ocean Co., Ltd based on price (€).

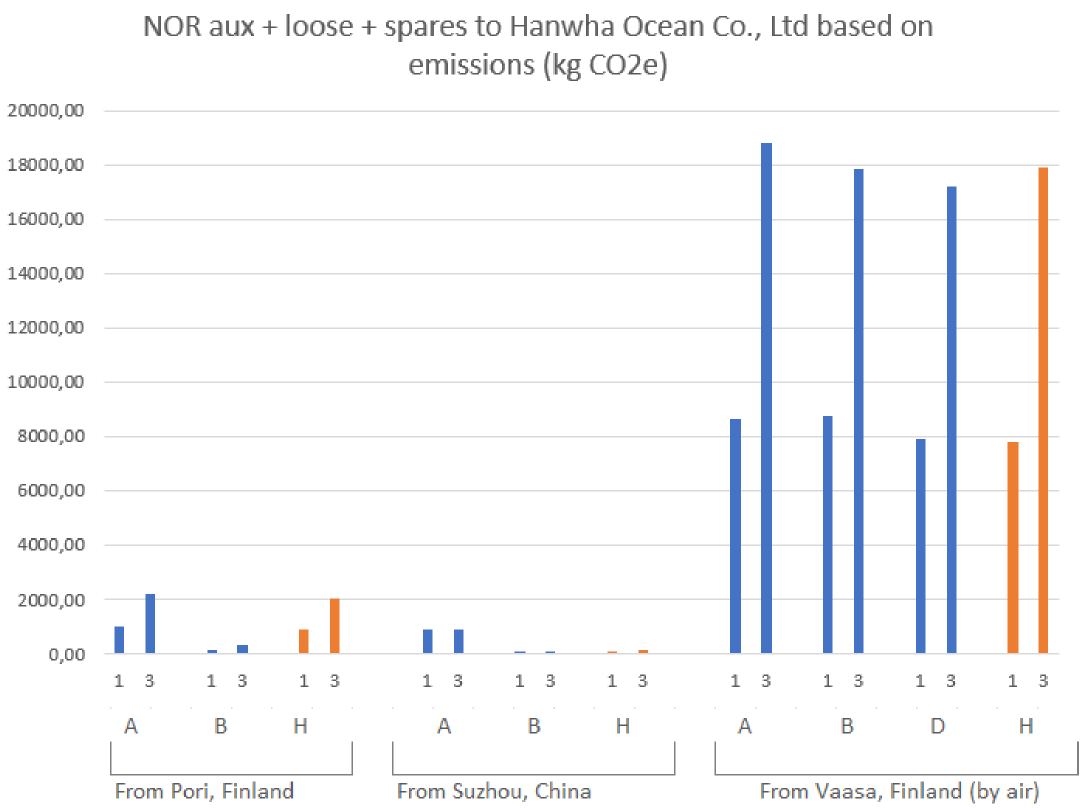

Figure 37. NOR aux, loose, and spares to Hanwha Ocean Co., Ltd based on emissions (kg $CO2e$).

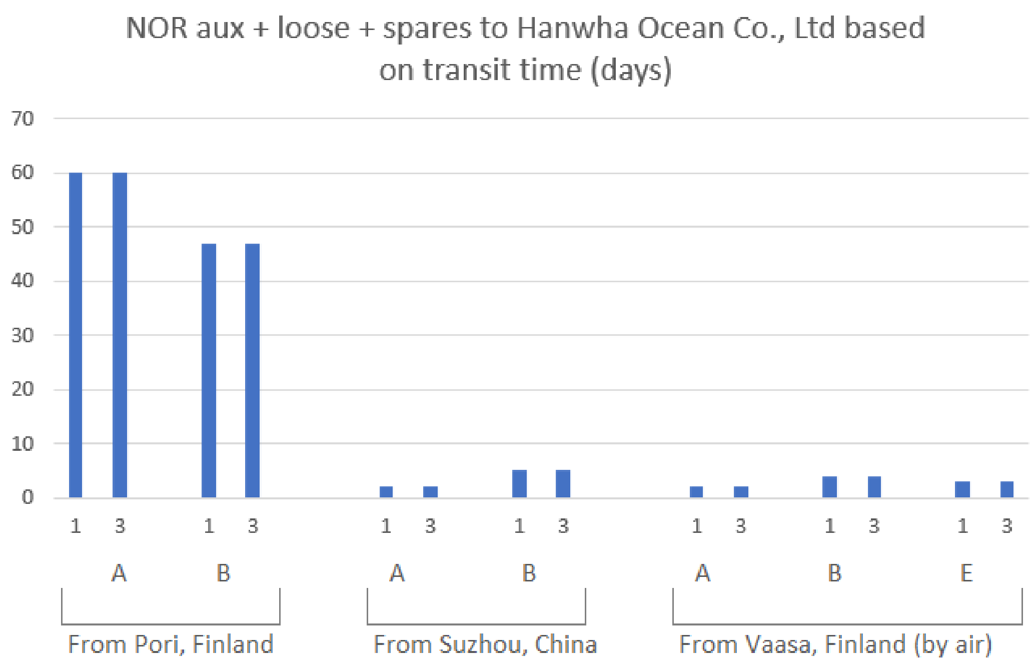

Figure 38. NOR aux, loose, and spares to Hanwha Ocean Co., Ltd based on transit time (days).

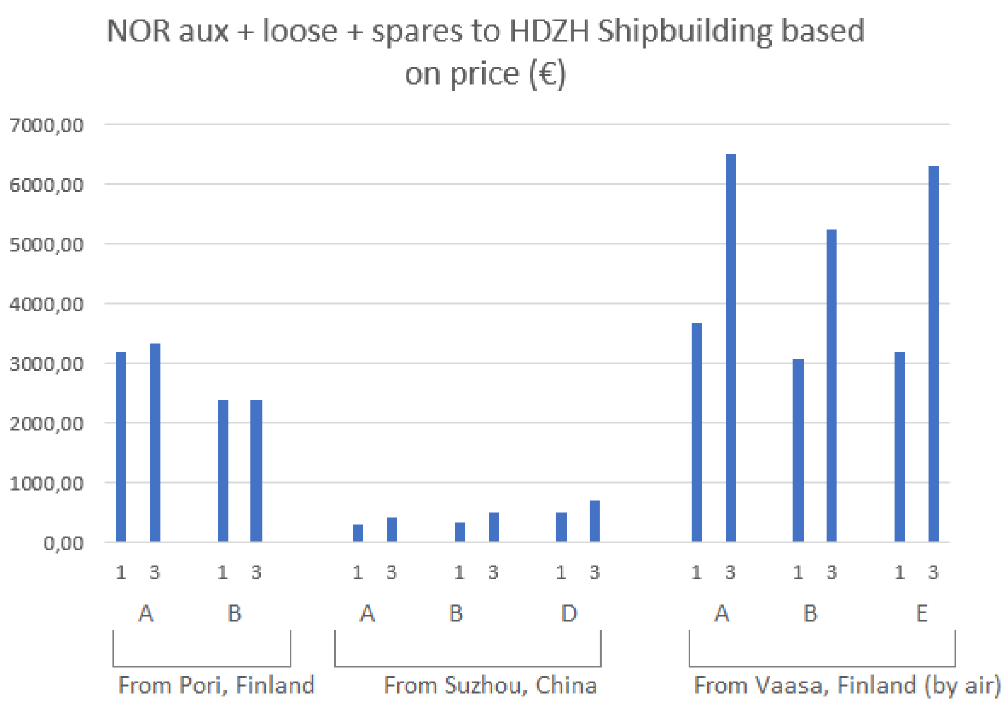

Figure 39. NOR aux, loose, and spares to HDZH Shipbuilding based on price (€).

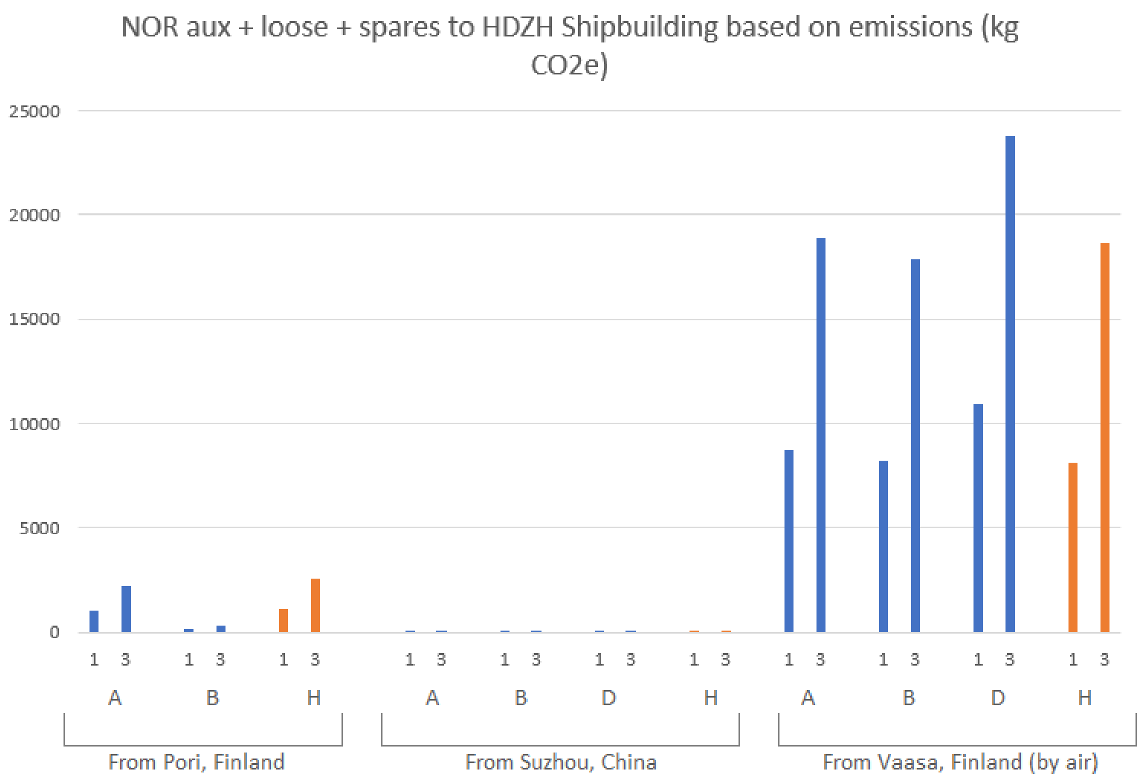

Figure 40. NOR aux, loose, and spares to HDZH Shipbuilding based on emissions (kg CO_2e).

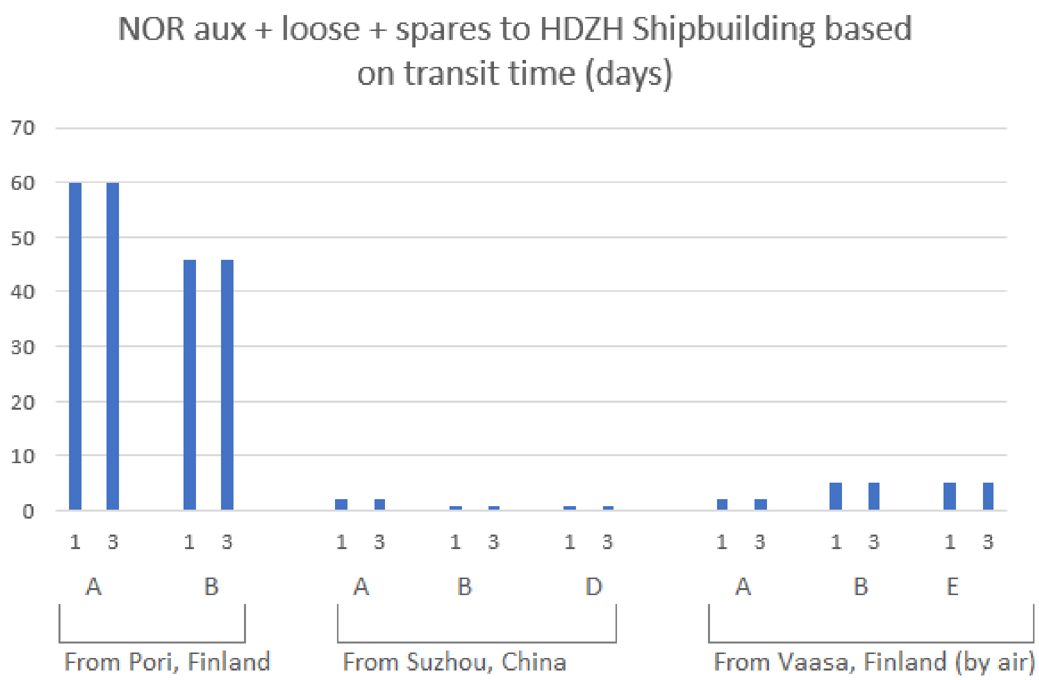

Figure 41. NOR aux, loose, and spares to HDZH Shipbuilding based on transit time (days).

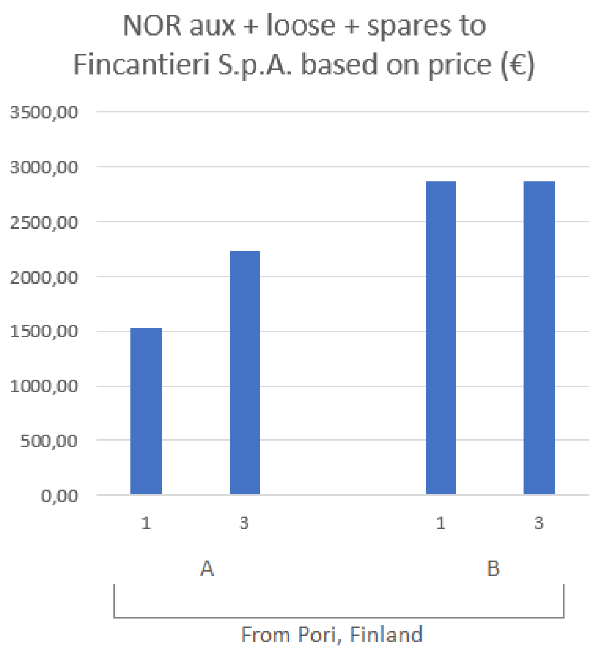

Figure 42. NOR aux, loose, and spares to Fincantieri S.p.A. based on price (€).

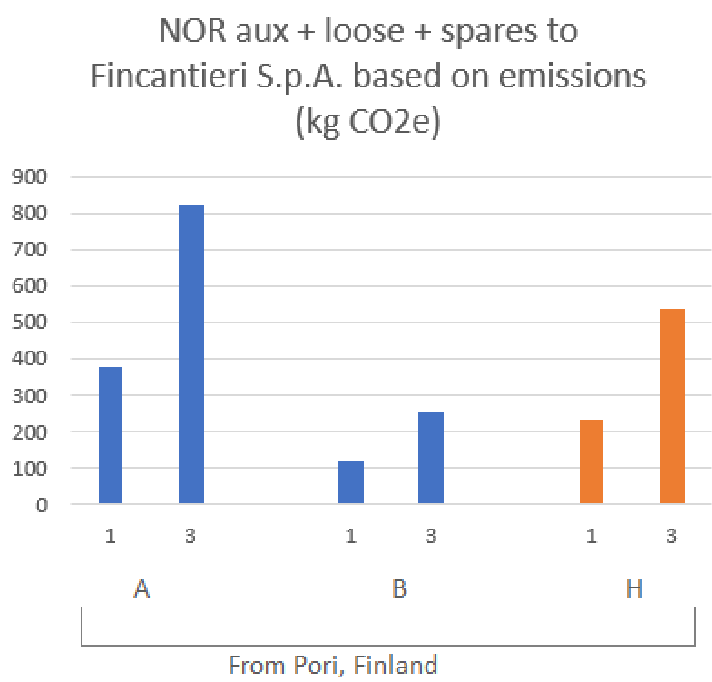

Figure 43. NOR aux, loose, and spares to Fincantieri S.p.A. based on emissions (kg CO_2e).

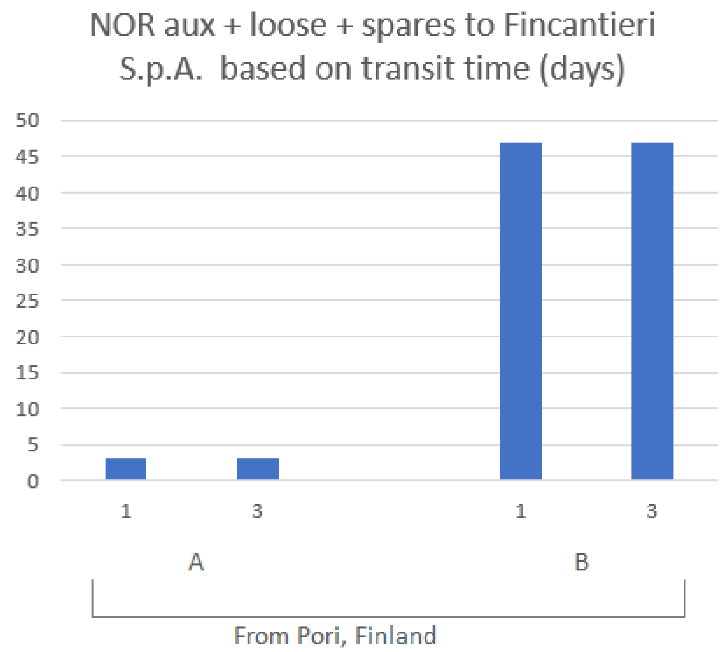

Figure 44. NOR aux, loose, and spares to Fincantieri S.p.A. based on transit time (days).

5.4 Summaries per project

In this chapter, the results will be presented per project. As mentioned earlier, case 1 is the smallest project, case 2 is a medium sized project and case 3 is the biggest project with most quantity of units and most weights. These tables are based on the quotations received from the forwarding companies. The lowest value for price, emissions, and transit time are being mentioned, as well as the highest value. The total transportation costs, emissions and transit time per project are also shown on a separate line.

Table 18. A summary of the results for case 1.

Case	Departure point	Destination point	Shipment	Price (€)	Emissions kg CO2e	Transit time (days)
1	Europe	HDZH Shipbuilding	NOR aux, loose, spares	2385,00 - 3207,00	140,13 - 995,41	46 - 60
			NOR elements	3339,00 - 3590,00	673,42 - 3984,86	44 - 60
			NOR reactor, mixing	17035,00 - 39945,00	1322,28 - 10175,31	49 - 60
			IN TOTAL	**22759,00 - 46742,00**	**2135,83 - 28266,58**	**49 - 60**
1	Asia	HDZH Shipbuilding	NOR aux, loose, spares	320,00 - 500,00	19,00 - 23,53	1 - 3
			NOR elements	1515,00 - 2185,00	124,98 - 131,16	2 - 4
			NOR reactor, mixing	715,00 - 1495,00	100,93 - 233,82	1 - 2
			IN TOTAL	**2550,00 - 4180,00**	**244,91 - 388,51**	**2 - 4**
1	Europe	Hanwha Ocean Co., Ltd	NOR aux, loose, spares	2295,00 - 2650,00	154,46 - 1025,78	47 - 60
			NOR elements	3267,00 - 4435,00	728,99 - 3868,32	55 - 57
			NOR reactor, mixing	15915,00 - 41875,00	1413,58 - 9892,77	40 - 60
			IN TOTAL	**21477,00 - 48960,00**	**2297,03 - 14786,87**	**55 - 60**
1	Asia	Hanwha Ocean Co., Ltd	NOR aux, loose, spares	1925,00 - 2125,00	42,38 - 868,53	2 - 5
			NOR elements	314,00 - 584,00	158,32 - 306,34	1 - 2
			NOR reactor, mixing	8186,00 - 10207,00	304,98 - 314,15	2 - 5
			IN TOTAL	**10425,00 - 12916,00**	**505,68 - 1489,02**	**2 - 5**
1	Europe	Fincantieri S.p.A.	NOR aux, loose, spares	1528,00 - 2870,00	116,78 - 376,35	3 - 47
			NOR elements	972,00 - 980,00	244,75 - 392,30	2 - 9
			NOR reactor, mixing	19295,00 - 20445,00	1083,68 - 4684,39	3 - 40
			IN TOTAL	**21795,00 - 24295,00**	**1445,21 - 5453,04**	**3 - 47**
1	Europe	Fincantieri S.p.A.	NOR aux, loose, spares	1528,00 - 2870,00	116,78 - 376,35	3 - 47
	Asia		NOR elements	5640,00 - 6255,00	671,64 - 4136,76	60 - 71
			NOR reactor, mixing	30489,00 - 31960,00	1284,35 - 10166,23	39 - 40
			IN TOTAL	**37657,00 - 41085,00**	**2072,77 - 14679,34**	**60 - 71**

In the table for the mid-size project (case 2), the same values are used as for case 1 for the NOR aux, loose, and spares shipments. This because case 2 was excluded for NOR aux, loose, and spares in the RFQ part since the case is almost identical to case 1. There were only minor differences in volume and weight for these two projects and therefore the prices and emissions would not differentiate much.

Table 19. A summary of the results for case 2.

Case	Departure point	Destination point	Shipment	Price (€)	Emissions kg CO2e	Transit time (days)
2	Europe	HDZH Shipbuilding	NOR aux, loose, spares*	2385,00 - 3207,00	140,13 - 995,41	46 - 60
			NOR elements	3590,00 - 4085,00	1208,19 - 7179,02	44 - 60
			NOR reactor, mixing	17815 - 40557,00	2433,21 - 18659,97	49 - 60
			IN TOTAL	**23790,00 - 47849,00**	**3781,53 - 26834,40**	**49 - 60**
2	Asia	HDZH Shipbuilding	NOR aux, loose, spares*	320,00 - 500,00	19,00 - 23,53	1 - 3
			NOR elements	1745,00 - 2695,00	176,87 - 236,29	2 - 4
			NOR reactor, mixing	1495,00 - 2185,00	185,09 - 349,00	1 - 2
			IN TOTAL	**3560,00 - 5380,00**	**380,96 - 608,82**	**2 - 4**
2	Europe	Hanwha Ocean Co., Ltd	NOR aux, loose, spares*	2295,00 - 2650,00	154,46 - 1025,78	47 - 60
			NOR elements	4007,00 - 4435,00	1278,35 - 6969,95	55 - 57
			NOR reactor, mixing	18557,00 - 43367,00	2592,29 - 18141,83	40 - 60
			IN TOTAL	**24859,00 - 50452,00**	**4025,10 - 26137,56**	**55 - 60**
2	Asia	Hanwha Ocean Co., Ltd	NOR aux, loose, spares*	1925,00 - 2125,00	42,38 - 868,53	2 - 5
			NOR elements	450,00 - 1164,00	285,23 - 551,80	1 - 2
			NOR reactor, mixing	11165,00 - 13665,00	559,29 - 571,10	2 - 5
			IN TOTAL	**13540,00 - 16954,00**	**886,90 - 2291,43**	**2 - 5**
2	Europe	Fincantieri S.p.A.	NOR aux, loose, spares*	1528,00 - 2870,00	116,78 - 376,35	3 - 47
			NOR elements	1195,00 - 1650,00	440,93 - 706,76	2 - 9
			NOR reactor, mixing	19295,00 - 54945,00	1987,30 - 8590,46	3 - 40
			IN TOTAL	**22018,00 - 59465,00**	**2545,01 - 9673,57**	**3 - 47**
2	Europe	Fincantieri S.p.A.	NOR aux, loose, spares*	1528,00 - 2870,00	116,78 - 376,35	3 - 47
	Asia		NOR elements	6255,00 - 7189,00	1197,15 - 7412,68	60 - 71
			NOR reactor, mixing	34797,00 - 34796,00	2355,30 - 18643,31	39 - 40
			IN TOTAL	**42580,00 - 44855,00**	**3669,23 - 26432,34**	**60 - 71**

* Same values as for case 1 have been used for case 2 NOR aux, loose, spares.

Table 20. A summary of the results for case 3.

Case	Departure Point	Destination point	Shipment	Price (€)	Emissions kg CO2e	Transit time (days)
3	Europe	HDZH Shipbuilding	NOR aux, loose, spares	2385,00 - 3331,00	304,98 - 2166,31	46 - 60
			NOR elements	8194,00 - 13895,00	4445,80 - 22333,89	44 - 60
			NOR reactor, mixing	28664,00 - 65985,00	4772,53 - 36599,87	49 - 60
			IN TOTAL	**39243,00 - 83211,00**	**9523,31 - 61100,07**	**49 - 60**
3	Asia	HDZH Shipbuilding	NOR aux, loose, spares	430,00 - 715,00	42,00 - 51,22	1 - 3
			NOR elements	4805,00 - 7735,00	650,82 - 735,10	2 - 4
			NOR reactor, mixing	2117,96 - 3450,00	363,04 - 841,04	1 - 2
			IN TOTAL	**7352,96 - 11900,00**	**1055,86 - 1627,36**	**2 - 4**
3	Europe	Hanwha Ocean Co., Ltd	NOR aux, loose, spares	2295,00 - 2770,00	331,80 - 2232,41	47 - 60
			NOR elements	7970,00 - 17215,00	4703,97 - 21683,49	55 - 57
			NOR reactor, mixing	28562,00 - 68543,00	5084,53 - 35583,58	40 - 60
			IN TOTAL	**38827,00 - 88528,00**	**10120,30 - 59499,48**	**55 - 60**
3	Asia	Hanwha Ocean Co., Ltd	NOR aux, loose, spares	2125,00 - 2673,00	92,23 - 868,53	2 - 5
			NOR elements	1350,00 - 3422,00	1049,57 - 1716,64	1 - 2
			NOR reactor, mixing	16612,00 - 17525,00	1096,98 - 1129,98	2 - 5
			IN TOTAL	**20087,00 - 23620,00**	**2178,78 - 3715,15**	**2 - 5**
3	Europe	Fincantieri S.p.A.	NOR aux, loose, spares	2234,00 - 2870,00	254,17 - 819,05	3 - 47
			NOR elements	1583,00 - 4950,00	1622,48 - 2198,72	2 - 9
			NOR reactor, mixing	32590,00 - 71556,00	3897,89 - 16849,41	3 - 40
			IN TOTAL	**36407,00 - 79376,00**	**5774,54 - 19897,18**	**3 - 47**
3	Europe	Fincantieri S.p.A.	NOR aux, loose, spares	2234,00 - 2870,00	254,17 - 819,05	3 - 47
	Asia		NOR elements	13855,00 - 24525,00	4405,19 - 23185,24	60 - 71
			NOR reactor, mixing	54379,00 - 55067,00	4169,69 - 36567,18	39 - 40
			IN TOTAL	**70468,00 - 82462,00**	**8829,05 - 60571,47**	**60 - 71**

6 Conclusion

The purpose of this thesis was to study the transportation costs, emissions, and transit time for the three different shipments (NOR reactor and mixing, NOR elements, and NOR aux, loose, and spares) to be delivered to both Asia and Europe and how significant the differences are if departure point is Asia versus Europe for the shipments. The research question was "How much can Catalyst Systems reduce their transportation costs, environmental impacts, and delivery time?".

6.1 Summary of findings

After summarizing and analyzing the results, it can be stated that the larger a project to be transported is (size and volume), the more expensive will the transportation costs be and the greater the environmental impacts in terms of CO_2e value will be. Further, it can be stated that the size of the shipment does not have an impact on transit time if departure point and destination point are the same. These conclusions can be applied to the cases that have been studied in this research, which all are between 1,4 tons to 51,3 tons. In below price comparisons, both the cheapest and the most expensive quotation for every option has been taken into consideration. There were big differences in the CO_2e value provided from the different forwarding companies. Forwarding company B did in many cases provide much lower CO_2e values than forwarding company A did. In below comparison, all CO_2e values have been taken into account.

For NOR reactors and mixing, shipments being transported to Hanwha Ocean Co., Ltd in South Korea, it will be approximately 7 700 – 67 000 € cheaper (depending on which forwarding company is being selected) in transportation costs by shipping these from the supplier in China instead of from the supplier in Estonia. The transit time is also 35 - 45 days shorter from the supplier in China compared to from the supplier in Estonia. Depending on which transport company that is being selected, the CO_2e value is 700 – 24 500 kg lower, if choosing the supplier located in China.

For NOR reactors and mixing shipments being transported to HDZH Shipbuilding located in China, it will be approximately 16 000 – 62 500 € cheaper in transportation costs by shipping these from the supplier in China instead of from the supplier in Estonia. In this case, the transit time would be 46 – 56 days shorter from the supplier in China. When it comes to the emissions, the CO_2e value is 1 900 – 35 800 kg lower if arranging transportation from China instead of Estonia depending on which forwarding company is being selected.

When transporting NOR reactor and mixing to Fincantieri S.p.A. in Italy, the transportation costs will be 11 100 – 24 800 € lower, depending on the size of the project, if ordering the units included in the shipment from Estonia instead of China. The transit time by sea is the same from both departure points, but if road transport is chosen for the shipment from Estonia, the transit time will be reduced to three days. Depending on which forwarding company that arranges the transportation, the emissions will be 200 – 32 700 kg CO_2e lower if arranging the transportation from Estonia instead on from China.

For the NOR element shipments with destination Hanwha Ocean Co., Ltd, the transportation costs will be 2 900 – 15 800 € higher if arranging the transport from Germany instead of from Korea. The transit time will be 53 – 56 days faster for the shipment within Korea than for the transport from Germany to Korea. Depending on which forwarding company that arranges the transportation, the emissions will be 550 – 24 500 kg CO_2e lower if arranging the transportation from South Korea instead on from Germany.

The transportation costs for NOR element shipments with destination point HDZH Shipbuilding will be between 1 800 – 9 000 € more expensive if arranging the transport from Germany instead of from South Korea. The transit time will be approximately 40 – 55 days shorter from South Korea compared to Germany. The CO_2e value will also be 550 – 22 000 kg lower if departure point is South Korea instead of Germany.

For the NOR element shipments with destination point Fincantieri S.p.A. the transportation costs will be 4 600 – 23 000 € cheaper if arranging the transport from Germany compared to Korea. The transit time is also between 50 – 70 days longer from Korea than from Germany. Depending on which forwarding company that arranges the transportation, the emissions will be 400 – 21 000 kg CO_2e lower if arranging the transportation from Germany instead on from South Korea.

For NOR aux, loose, and spares shipments with destination point Hanwha Ocean Co., Ltd, the transportation costs are approximately 350 € cheaper for case 1, and 170 € cheaper for case 3 if arranging the transport from China instead of from Finland. The transit time is between 42 – 58 days faster from China than Finland. The CO_2e value for case 1 and case 3 will be approximately 100 – 1 200 kg lower if arranging the transportation from China instead of by sea from Finland. If air freight would be required from Finland, the transportation costs would be around 1 000 – 3 000 € more, and the CO_2e value would be 7500 – 17 000 kg higher compared to sea freight. However, the transit time would be reduced from 47 – 60 days to 2 – 4 days.

The transportation costs for NOR aux, loose, and spares shipments to HDZH Shipbuilding is around 2 000 € cheaper for both cases (1 and 3) if the transport is to be arranged within China, than from Finland to China by sea. The transit time would be 45 – 60 days longer if the departure point is Finland. The CO_2e value for case 1 and case 3 will be approximately 120 – 2 100 kg lower if arranging the transportation from China instead of by sea from Finland. If air freight would be required from Finland, the transportation costs would be around 700 – 3 000 € more, and the CO_2e value would be 8 000 – 17 500 kg higher compared to sea freight. However, the transit time would be reduced from 46 – 60 days to only 1 – 2 days.

For NOR aux, loose, and spares shipments with destination point Fincantieri S.p.A., the results show that it is 600 – 1 300 € cheaper to book the transport by road instead of by sea. It is also approximately 45 days faster by road than by sea. However, the emissions are lower by sea. For case 1 the value is 250 kg CO_2e lower by sea and for case 3 the value is 550 kg CO_2e lower by sea.

6.2 Discussion

The results of this thesis show that the transportation is cheaper, faster, and more environmentally friendly when using Asian suppliers for projects located in Asia and European suppliers for projects located in Europe. The bigger the project is, the more significant are these values as well. Being well on time with the projects helps the planning of the transportation and making the decision on which transport mode and which forwarding company to be selected. Delays earlier in the process, for instance in the production, create challenges for the transport planners. In these cases, transport decisions are often based on transit time without taking environmental impacts into consideration.

The results of this thesis show also that it is of great importance to send out RFQs to several forwarding companies, since the differences in transportation costs and emissions are sometimes really significant. Seven different forwarding companies received RFQs for this study, and only two forwarding companies responded to all RFQs. In total, five different forwarding companies provided at least one quotation. The RFQs could have been sent out to more companies in order to receive more quotations.

In terms of reliability and validity, there are significant differences in the value of CO_2e emissions provided from the transport companies. The values calculated with the NTM Calc 4.0 Basic tool are in the most cases more similar to transport company A's provided values than transport company B's values. However, there are factors influencing the CO_2e emissions that the NTM Calc 4.0 Basic tool does not take into account. These factors are speed (including acceleration), number of stops, empty runs and cargo specifications. However, empty runs are easy to calculate separately and add if needed.

This study has successfully determined the transportation costs, CO_2e emissions and transit time for different transport routes and different shipments. The results, especially prices, are valid for transports for spring and summer 2024. When it is possible again to use the Suez Canal for sea transports, the transit time and CO_2e emissions will be reduced as the distance is much shorter using the Suez Canal instead of going around Cape of Good Hope. Future research could also take the production costs and environmental impacts into consideration as well as the production time for the different suppliers.

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