Master's degree thesis

LOG950 Logistics

A comparative assessment of the environmental impacts of China-Scandinavia supply chains: A case comparison of the route Zhengzhou-Oslo

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Preface

This thesis was written as a part of our Master program at Molde University College. The process of writing the thesis started out in December 2018 and was finished in May 2019.

The thesis is the result of both author's growing interest for transportation after choosing this specialization for the semester last spring. Especially the course on Marine Transportation awakened our enthusiasm for shipping and container transport. We see the involvement of many modes to transport goods from point A to point B as an interesting topic to look at further with emissions as the main focus.

During the completion of this thesis we have been on a continuous journey of hard work and learning which has helped us grow as students ready to take the next step into life. Because of our ever-growing interest in the transportation sector it has been an exciting process this semester, and we feel that our final result is satisfactory and that all our hard work and periods of frustration was worth the effort.

We want to thank our fellow students who we have shared this journey with.

We want to especially thank our supervisor Harald M. Hjelle for his exceptional help throughout the entire process of creating this thesis.

Abstract

This thesis concerns the topic of sustainability of transportation by focusing on the environmental footprints of three different modes of transportation. This topic has become relevant especially in later years because of the increased competitiveness of railway transportation because of the OBOR currently being developed by China. We want to see how the railway from China to Europe can compare to the maritime route through the Suez-Canal in an environmental context.

The focus has been on four of the main air pollutants connected with land and maritime transportation, CO_2, NO_x, SO_2 and PM. Because of this we have focused on answering questions pertaining to the scope of the trade between China and Europe, what factors that are most important when evaluating the environmental impact of containerized supply chains and the comparative environmental footprint of the selected designs.

Due to the size of the assessment, we decided to use a mixed methods approach. This means we have combined some quantitative aspects to a qualitative approach. The first step was to find relevant emission factors to the selected transportation methods and calculate the emissions connected with each route. The second step was to look at the characteristics of the routes to assess how emissions might affect human health, ecosystems and the environment. From there on we could discuss the results we found and draw some conclusions to the environmental strengths and drawbacks between the modes.

Based on our calculations and analysis we have seen that there are both strengths and weaknesses from all modes. While maritime transportation will continue to be the dominant transportation method for long distances, we see that they have higher emissions than railway when it comes to NO_x and SO_x. On the other hand, we see that railway and trucks have high emissions of CO_2 thanks to the production of electricity in the different countries for railway, while trucks are high because of the combustion of diesel.

Abbreviations

CO_2 – Carbon Dioxide

EU – European Union

FEU – Forty-foot equivalent unit

GHG – Greenhouse Gas

HFO – Heavy Fuel Oil

IATA – International Air Transport Association

IFEU - Institute for Energy and Environmental Research

IMO – International Maritime Organization

IPA – Impact Pathway Approach

LCA – Life-Cycle Assessment

MDO – Marine Diesel Oil

MJ - Mega Joule

NOK – Norwegian Krone

NO_x – Nitrogen Oxide

NSR – Northern Sea Route

OBOR – One Belt One Road

PEF – Primary Energy Factor

PM – Particulate Matter

PRC – People's Republic of China

SECA – Sulfur Emission Control Area

SITC – Standard International Trade Classification

SO_2 – Sulfur Dioxide

SO_x – Sulfur Oxide

TEU – Twenty-foot equivalent unit

TTW – Tank-To-Wheel

USSR – Union of Soviet Socialist Republics

WTT – Well-To-Tank

WTW – Well-To-Wheel

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1.0 Introduction

In later years, China has started to focus on what is known as the One Belt One Road (OBOR) initiative where trains are becoming a more viable option for container freight to Europe. At the same time, container ships are becoming larger, with some being able to carry as much as 22 000 TEU's (Twenty-foot Equivalent Units) on one ship. As the focus on reducing the damaging effects transport causes on the environment is increasing, OBOR might prove to be a good alternative to sea freight. However, shipping has for many years been looked at as the go-to option for environmental sustainability, and with larger and more efficient ships it is by many still considered the greenest mode of transport. In our thesis we will compare the two modes shipping and railway in a theoretical supply chain from the city of Zhengzhou in China, to Oslo in Norway. The aim of the thesis is to compare the two modes in the context of environmental impact to see which one is greener. Our focus will be on airborne pollutants and the effects they have on climate, ecosystems and human health.

Our goal is to evaluate the environmental impacts of two railway alternatives and one sea alternative. The aim is to get an overview on how the different alternatives compare in an environmental perspective. This involves looking at what pollutants are relevant and what impact they have on the environment, ecosystems and human health. In order to establish a context, the thesis also aims to find out how large the trade between the two countries are. Also, which factors that are important when evaluating the environmental impact of the supply chains.

The thesis will use a combination of qualitative and quantitative methods, also known as a mixed method study. Thorough research on different factors that affect emissions and emission factors will be considered to create a dataset which allows for a quantitative comparison between the modes. Further, the impacts of each individual pollutant are established. Our methodology is inspired by the Impact Pathway Approach (IPA). However, we will focus on the external effects of emissions to air but will not convert them to monetary values.

The paper will be divided into multiple chapters which will cover different aspects related to the case, methodology and analysis. Our thesis will start with a brief introduction to our topic and the background for its selection. Further, in chapter two, the research methodology will be presented. Moving on to chapter three we will present a literature review that covers previous research on the topic in addition to important background information. From this an analysis will be made in chapter four where both the quantitative and qualitative data will be presented. This data will further be discussed in chapter five to get a balanced view of our findings. Lastly, in chapter six our conclusion will be presented in addition to the limitations of our study and suggestions to future research.

1.1 Background

The background for our thesis is the growing interest in greener and more sustainable transport solutions. Both the private sector and policy makers are striving to reduce emissions to get in line with global agreements such as the Paris Agreement (Savaresi, 2016). Transportation plays a key role in reducing greenhouse gas (GHG) emissions and subsequently global warming. As of 2015, the transport sector accounted for 23% of energy related CO_2 emissions (International Energy Agency, 2017). It is therefore important to investigate if a shift to alternative modes of transport could be favorable in an environmental perspective.

1.2 Research problem

Our research problem is based on the emerging focus on green logistic solutions and the recent development of the OBOR, with focus on the container trade between China and Europe. This initiative was presented by the Chinese president Xi Jinping in 2013 and is an attempt to reinvigorate the “silk road” between China and Europe through development of infrastructure and cooperation with the countries involved along the route.

Our research problem is ***“A comparative assessment of the environmental impacts of China-Scandinavia supply chains: A case comparison of the route Zhengzhou-Oslo”***

This will also be defined further in chapter 2.

1.3 Limitations of study

There are several limitations that we have had to take into consideration when developing the topic of our thesis. One relates to the availability of data as the development of the OBOR initiative is a relatively new topic. However, as our focus is on the emission side of transportation, we can focus on previous research within that field, and use papers pertaining to the OBOR as supplementary literature.

Another limitation is the types of emissions we want to look at for this thesis. Considering the amounts of emissions that can be connected to transportation, it would be too comprehensive to look at every pollutant related to this. Because of this we have decided to focus on the four major air pollutants: Nitrogen Oxide (NO_x), Sulfur Oxide/Sulfur Dioxide (SO_x/SO_2), Carbon Dioxide (CO_2) and Particulate Matters (PM) as they can be connected to the three different routes we are comparing.

Lastly, we have noticed the lack of relevant benchmarks that can help point us in the right direction. Few papers have covered the comparisons of two or more modes from Eastern Asia towards Europe which means that we will have to look at other papers with cases that can be similar in nature.

2.0 Research methodology

We can define research methodology as a way to systematically solve a research problem. In this chapter, we will put forward the various steps that are adopted for the sake of studying the research problem, along with the logic behind them. The importance of research methodology cannot be understated, as the choice of methodology will alter the outcome of the research. Because of this, it is important that the research methodology fits well with the research problem at hand (Kothari, 2004).

The research methodology must not be confused with research method, something Kothari (2004) further elaborates on: *"Thus, when we talk of research methodology we not only talk of the research methods but also consider the logic behind the methods we use in the context of our research study and explain why we are using a particular method and technique and why we are not using others so that research results are capable of being evaluated either by the researcher himself or others".* Therefore, we will describe the research methodology and discuss how our thesis can be linked up to our strategy, questions, design and method that we will focus on.

2.1 Research strategy

It is important to decide what research strategy fits well with our thesis and the problem at hand. First, we need to decide whether we will pursue a qualitative approach or a quantitative approach. Bryman (2011) has defined both and mentions the importance of not looking at them in light of each other. By this he means that often qualitative research can be addressed in terms of what quantitative research is not. It is therefore important to look at them individually and see which one fits for our thesis.

2.1.1 Qualitative research

Qualitative research is defined by Bryman (2011) as "*a research strategy that usually emphasizes words rather than quantification in the collection and analysis of data"* Qualitative research can be divided into two major parts as described by Patton (2005):

Participant observation. "*Data is gathered in a natural environment which engages normal behavior".*

In-depth interviewing. By using open ended questions, it allows for the informants to answer from their "own frame" of reference rather than being restricted by pre-arranged questions. The goal here is to get as many details as possible.

Furthermore, five features of qualitative research can be defined:
Naturalistic. With a focus on actions in a natural environment.
Descriptive data. The use of pictures and words instead of numbers.
Concern with process. The process is more of a concern rather than simple outcomes.
Inductive. Analyzing the data more inductively means that they do not seek to find data to "*prove or disprove hypotheses that they have prior to their study"* (Patton, 2005).
Meaning. Interplay between researcher and the interviewee. What did he/she mean by his/her answer?

2.1.2 Quantitative research

"*Entailing the collection of numerical data and as exhibiting a view of the relationship between theory and research as deductive, a predilection for natural science approach, and an objectivist conception of social reality"* (Bryman, 2011).

For quantitative research the aim is to prove or disprove a hypothesis by collecting data and analyzing it to find answers. Quantitative research aims to look at the numbers in datasets, and to let them speak for themselves. Bryman (2011) uses a figure to show the process of quantitative research through 11 steps:

1. Elaborate a theory
2. Devise hypothesis
3. Select research design
4. Devise measures of concept
5. Select research site(s)
6. Select research subjects/respondents
7. Administer research instruments/collect data
8. Process data
9. Analyze data
10. Develop findings/conclusions
11. Write up findings/conclusions

When deciding what type of research strategy and design to use, we must consider what our thesis aims to achieve. With emissions from different modes of transport, in different corridors being the focus, numbers will be important as this is a comparative study. However, our thesis will be combining both qualitative and quantitative aspects and combine them to give answers to the research questions at hand.

2.2 Research problem and questions

When conducting research, it is important to have some research questions that further emphasizes what is to be explored. The research questions are important in the sense that they will influence the writing-up of the study manuscript, the interpretation of results and the choice of study design (Stone, 2002). Stone (2002) further emphasizes the importance of clearly refined research questions, in which the following are the most important for our thesis and research problem:

To promote clarity of thought

When making a research question, it is often easy to fall into the temptation of addressing too many questions in one study. As such, the research questions can help with focusing on the main objectives of the study.

To inform the choice of research methodology

Sackett and Wennberg (1997) elaborates on how the research question are what guides the research methodology. According to them, the question being asked will determine the appropriate research architecture, strategy and tactics to be used.

To guide data-analysis

Clear objectives should determine the analysis plan and guard against "data dredging" (to search data for "significant" results), something that can produce misleading results.
Based on this theory, we have created a selection of research questions that fit well with our thesis.

2.2.1 Research problem

Our research problem is also based on the three points made above which aims to negate a too broad approach on the research. Our focus is to compare the different modes, and their impacts on the environment from China to Norway.

The three research questions we have come up with have been designed to keep the subject narrow and to the point, but at the same time connect factors such as trade volumes to emissions.

Our research problem is as the title shows: "*A comparative assessment of the environmental impacts of China-Norway supply chains: A case comparison of the route Zhengzhou-Oslo"* with a focus on containerized transport and four types emissions to air to keep the thesis specified. The background for the selection of this case is related to the scope and relevancy of this trade corridor. Trade between China and Norway is growing, and that also means the need for transport. As more focus has shifted to sustainable transport solutions, the research problems highlight the need for a thorough analysis of how the different modes of transport compare in an environmental perspective. In addition, the results arising from our research could set an example for other comparisons of similar nature, but between different regions and countries.

2.2.2 Research questions

RQ. 1 How big is this trade in terms of total annual container volumes?
First, it is important to establish how large the annual containers volumes are in this trade. The reason for this is that it establishes the relevancy of the research. If results show that the volumes are significant, this can make the research more valuable and put the following research questions in a context. Within this category, it will also be interesting to see how the modal split is distributed among the different modes of transport.

RQ. 2 Which factors are most important when evaluating the environmental impact of containerized supply chains?
The term environmental impact is vague as it does not further specify what environmental impacts we are referring to. When thinking of environmental impact, it is often seen as a synonym relating to airborne pollutants. However, the term can also encompass other forms of environmental impacts such as noise pollution and physical footprints, even though these are not relevant for our thesis. Because of this, we want to exclusively look at how the different types of emissions to air affect the general environment. We also want to make calculations with baseline assumptions as well as alternative assumptions to evaluate what factors influence emissions. These factors encompass variables such as operational speed of vessels and the electricity mix in different countries.

In addition, we want to look at how emissions affect areas with higher populations compared to more rural areas along the different corridors. The aim is to find out how to weight the different emissions to air and how they are related to the different modes of transport.

RQ. 3 What is the comparative environmental footprint of the selected designs?

Finally, we want to compare the environmental footprint of the different modes of transport to get a good overview. This is a question that will ultimately help with concluding the thesis. The reason is that it will result in a complete dataset of information from which we can discuss and reflect over. Furthermore, it will combine the knowledge gained from the earlier research questions.

2.3 Research design

With the focus being on both information gathering as well as data collection it can be hard to see whether the research design is mostly qualitative or quantitative. Our goal is to find numerical data that can give us answers as to which mode of transport has the lower environmental impact. This part of the thesis will be quantitative; however, we also want to describe and explore the results in a qualitative way. Therefore, we have looked at Creswell and Creswell (2017) and their mixed methods study.

"*With the development and perceived legitimacy of both qualitative and quantitative research in the social and human sciences, mixed methods research, employing the combination of quantitative and qualitative approaches, has gained popularity" (Creswell and Creswell, 2017).* By using this method, we can combine the strengths of both qualitative and quantitative research. Furthermore, we will investigate the aspects of mixed method to see what defines it and makes it work. To do this, Creswell and Creswell (2017) mentions the importance of four aspects of mixed methods. These are timing, weighting, mixing and theorizing.

- **Timing.** Proposal developers need to focus and consider the timing of both their qualitative and quantitative data collection. By this they mean that the focus needs to be on whether the data collection is sequential or gathered at the same time. An example given by Creswell is that if qualitative data is gathered first, the intent is to explore the topic before gathering data on the subjects in question.

If this data is collected concurrently it can be because of time restrictions, or because it is easier to handle the data simultaneously. Which is, in our case, the approach we will use as the gathering of data will happen simultaneously.

- **Weighting.** Which study is getting the most attention or priority in the given study? In some cases, the weight might be equal, while in other it might emphasize one or the other. The weighting is mostly determined by which mode of research is most relevant for the study.
- **Mixing.** Mixing the data can be tricky as Creswell and Creswell (2017) mentions; "*mixing research questions is difficult at best when one considers that qualitative data consists of images and text and quantitative data, numbers."* If we look at this from our perspective, mixing will not be as relevant as we will focus on the numbers in this thesis, and later discuss the findings and evaluate them.
- **Theorizing or Transforming Perspectives.** *"A final factor to consider is whether a larger, theoretical perspective guides the entire design"* (Creswell and Creswell, 2017). Again, for our thesis this is not quite the case as the theoretical perspective of this thesis is to gain insight into what the numbers mean in practice. The thesis is not based on these theories, but on the numbers.

By looking at these four aspects of mixed methods our collection of data will be mainly quantitative with some qualitative elements to support the findings. Our plan is to use secondary data to give an answer to the question of which intermodal setup that is environmentally greener compared to the others. Secondary data can be defined as follows: "*Secondary data is facts and information gathered not for the immediate study at hand but for some other purpose*"(A Churchill and Iacobucci, 2002). Examples of secondary data are scientific literature, books and statistics. Secondary data is the opposite of primary data, which is defined as: "*Primary data is facts and information collected specifically for the purpose of the investigation at hand*"(Rabianski, 2003). Examples of primary data are observation, interviews and surveys.

2.4 Research method

As mentioned earlier, we will use secondary sources for our collection of data. Firstly, we will give a description of the theme for this thesis to get the readers up to speed when it comes to what the thesis is about. Further, we will compare the different modes along the OBOR, both maritime and by rail and connect these with the emissions. This data will primarily come from secondary sources such as statistical bureaus such as Statistics Norway and scientific papers. One of the methods we have chosen to use for this thesis is the IPA.

2.4.1 Impact pathway approach

The methodology that will be used as an inspiration for our research is the IPA. This is an approach designed within the ExternE (External Costs of Energy) framework (European Commission, 2005). The ExternE project has its roots in 1991 as a collaboration between the EU and the US Department of Energy involving many actors. From the beginning of the project, multiple reports have been published covering the methodology and specific emission sources. From the creation of the methodology there has been 3 methodology updates, in the years 1994, 1998 and 2005. As of the day of writing, the 2005 methodology is the most recent (European Commission, 2005). The purpose of the methodology is to highlight the costs arising from human activities that are not paid for by the user. These are called external costs and will be further elaborated on in a separate chapter. Knowing the true costs of investments, consumption and technology can help both private businesses and policy makers make the correct choice to maximize welfare. One example of this usage in practice would be if one were to create a cost-benefit analysis. In this case a baseline alternative can be established, and the net benefit or drawback of a new activity evaluated. The results of the analysis could then be considered when making a final decision whether to go ahead with the activity or not. Another usage of the IPA is in green accounting. Green accounting in this case refers to the accounting of environmental and health impacts caused by human activity in a certain region or country. In the long term, one should be able to see whether there has been an improvement or not (European Commission, 2005). In both examples, there is a baseline scenario that is compared with a new scenario.

The ExternE framework consists of a bottom up approach going through various steps to get a better view of the whole picture regarding impacts of emissions to air. In a report written by the European Commission (2005), five steps have been highlighted to show the methodology:

1. *Definition of the activity to be assessed and the background scenario where the activity is embedded. Definition of the important impact categories and externalities.*
2. *Estimation of the impacts or effects of the activity (in physical units). In general, the impacts allocated to the activity are the difference between the impacts of the scenario with and the scenario without the activity.*
3. *Monetization of the impacts, leading to external costs.*
4. *Assessment of uncertainties, sensitivity analysis.*
5. *Analysis of the results, drawing of conclusions.*

While the methodology does not account for all the external effects, all the major ones are considered. More importantly, it manages to convert different impacts into one monetary unit, allowing for a fair comparison. Proven to be a detailed and reliable methodology, it has been used extensively by researchers on the subject of environmental impacts (Int Panis et al., 2004, Silveira et al., 2016).

Due to the limited scope of our study, we will rely on assumptions for the second step of the methodology where physical units are established. This is due to the sheer size of our routes which would render a thorough assessment too extensive. Further, the third step where physical units gets converted into monetary units will be skipped altogether. Partly due to the lack of concrete physical units to convert, and partly due to the very large variety of monetary conversion factors between the countries that are affected.

2.5 Summary of chapter

In this chapter we have presented our research problem and research questions that we are going to answer in this thesis. We have also looked at the research design which will be a version of mixed methods that combines qualitative and quantitative research. This is because we want to calculate emissions and compare the three intermodal setups with the help of these calculations.

Lastly, by using the IPA as inspiration, we have a good framework for our comparison. However, the IPA will not be followed to its entirety and the analysis will be more focused on the qualitative aspects of the method.

3.0 Literature review

The literature review is aimed at describing the theoretical foundation of our thesis with relevant literature that provides knowledge on the subject. As this thesis is focusing on the environmental aspect of container transport the theory and scientific papers will mainly focus on these areas. However, we will also touch upon some other relevant themes to supplement the main topic.

Looking at previous research surrounding the topic will also be essential as we want to bridge the gap between previous research and our own research. Relevant research on emissions from different modes of transport will be woven together to give us a good overview of the topic at hand.

Maritime and railway transport will be the focus when assessing and comparing the environmental impacts of emissions to air with the OBOR and the sea route from China to Norway as the comparative routes. Some topics about the technical possibilities and further development of this corridor will also be relevant to mention as they can be seen as emission reduction methods. There is a lot of research surrounding the environmental impact of transport. However, we have decided to narrow it down to air pollutants to keep the thesis more precise considering the scope of this assignment.

3.1 Previous research

When it comes to comparing and assessing the impacts that different modes of transport have on the environment, looking at previous research can give us an idea of what results we can expect from our own. As transport from China to Norway is a narrow topic it can be difficult to find previous research that specifically covers this area. Therefore, we look at other cases that are similar in nature. Looking at similar cases from other geographical locations can give us an indication as to how the emissions between railway and maritime transport differ on a smaller scale, and if they are similar to our case.

There is a good amount of scientific papers and previous studies on emissions from the different modes of transport. Fan et al. (2018) has done an extensive review on air emissions from transportation with a broad collection of previous papers surrounding the topic.

They state that the review "*aims to highlight the importance of considering air pollutants for decision making and evaluate the limitation of the current assessment of air emissions, particularly on transportation*".

Fan et al. (2018) mentions that environmental-related research dealing with emissions to air from transportation mainly focuses on land transportation, and the associated emissions factors. There are several papers that compare two different modes of transport from point A to point B even though they do not directly compare routes from China to Europe. In this paper, there is one example from the European Union (EU) where they have collected emission factors from various papers, with the latest being from 2017. By using these emission factors, they have compared a route from Rotterdam to Genoa where they compare the two modes road and short sea shipping. The results of their comparison can be seen in figure 1.

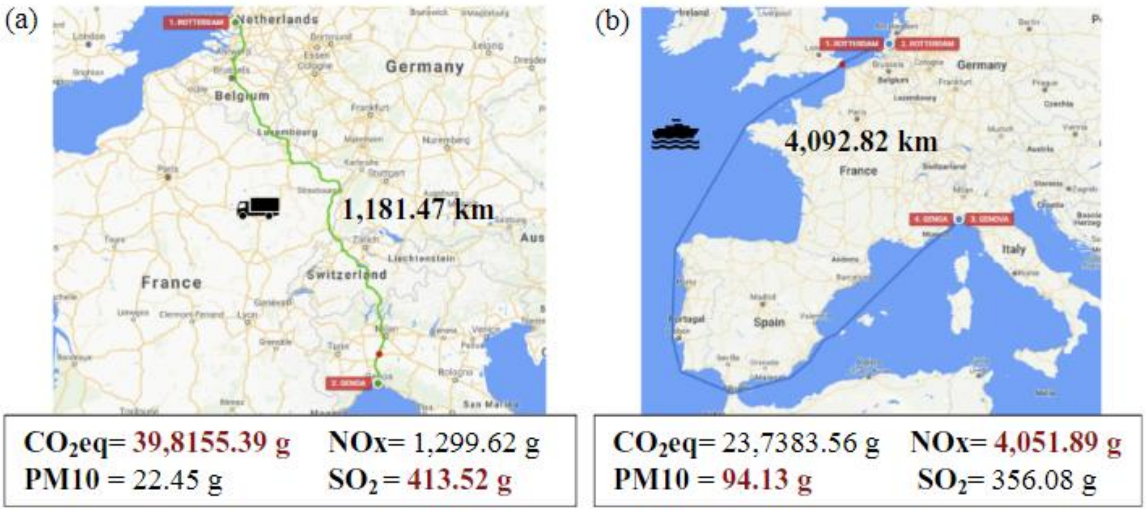


Figure 1: Emissions to air on the route Rotterdam-Genoa per ton of transported goods (Fan et al., 2018).

The study highlights the importance of including air pollutants rather than just focusing on GHG emissions, especially relating to cases where different modes of transport is compared. Their study shows that the amount of emissions is dependent on the transport mode, load capacity, fuel type and distance. The suggestions in this paper is based on the identified limitation of weighting and cost-based optimization and serves as a steppingstone to developing and improving the methods used for environmentally sustainable transport modes and systems.

Hjelle (2010) also presents several comparisons. These are for intermodal solutions and short sea shipping between Paris and Trondheim. The topic in the paper focuses on short sea shipping being at risk of losing its green label. A method with energy and emission factors are also included which results in calculations of total emissions.

Hjelle (2010) presents five different routes from Paris to Trondheim involving multiple modes of transport. The modes of transport vary from truck and ferries to intermodal setups combining both. Key performance indicators are also presented such as vessel types and operating speed, load factors, fuel and engine types. From this information a similar method is used for calculating the potential emissions connected with the routes. Firstly, through emission factors and energy, then by calculating total emissions from each transport chain. The results are then divided into different emission types such as CO_2, NO_x and SO_2. Furthermore, alternative scenarios are described and calculated to show how emissions might change with different load factors and its effects on primary energy consumption. By combining these results, Hjelle has looked at how all favorable assumptions can be combined to give maritime transport the edge above trucks for this route. However, this is clarified to not be very plausible. From this information a conclusion on emissions and impacts of these emissions are made for Ro-Ro-shipping versus road where the carbon emissions for shipping is not favorable. However, questions could be raised about the global warming effect from shipping versus road as well as SO_2 and NO_x emissions that on will be lower on average. This is especially related to health impacts as the emissions mostly take place far away from residential areas.

Similar to Hjelle, Svindland (2018) also investigated short sea shipping's competitiveness, but with a focus on the tightened restrictions on SO_x in Sulfur Emission Control Areas (SECA). The paper presents SO_2 emission calculations for two container feeder-vessels and conducts a comparative analysis of the environmental footprints of the short sea shipping service. This is done with a counterfactual road haulage operation pre- and post-regulation to see how SO_x regulations might help maritime operations uphold a green image compared to competing transport modes.

The conclusion of this paper highlights how Emission Control Areas (ECA) that are put in place to lower emissions, might result in higher CO_2 emissions because shipping companies might avoid these areas completely by routing, or by lowering their speed. Because speed is highly influential on fuel consumption and fuel cost, companies might decide to greatly lower the speed through ECA's where the fuel allowed is more expensive than regular Heavy Fuel Oil (HFO). Consequently, these tightened SO_2 restrictions aimed to reduce the environmental footprint of Short Sea Shipping (SSS) might result in a switch back to road for some of these areas. Paradoxically, this will lower SO_2 emissions because of trucks advantage here, but will lead to increased emissions of CO_2 and possibly causing more accidents and congestion.

There is also research on the case of moving goods from road to intermodal road-rail as an emission mitigation solution. One of these studies are presented by Pinto et al. (2018) in a case from Brazil. Their focus is the comparison of emissions between a road only and road-rail intermodal solution. Among other types of emissions to air they have included PM, CO_2 and NO_x but not SO_2. For their calculations they had several vehicle criteria such as type of truck, total gross weight ton, engine power and chassis structure. However, they have not considered any sensitivities or uncertainties for the calculations. Their study concluded that an intermodal road-rail solution would reduce emissions by up to 77,4%, be up to 43,48% more fuel efficient and up to 80% cheaper than operating solely with road transport.

Sandvik (2005) did a report on the environmental impacts of establishing two new short sea cargo routes from Norway to the United Kingdom and The Netherlands. The new routes from Kristiansund to Rosyth and Kristiansand to Eemshaven were planned as fast conventional ferries with an operating speed between 23 and 28 knots. In the study, a common export route running between Trondheim in Norway and Boulogne-sur-Mer in France were compared in an environmental aspect by looking at different routes. The new sea routes were compared to a standard route running from Trondheim to Oslo by truck, then a ro-pax leg from Oslo to Kiel, and finally a truck leg from Kiel to Boulogne-sur-Mer. In addition to this alternative, several different routes involving sea and rail were also considered. The study was performed using the OMIT computer program for calculating emissions and energy usage.

Different parameters were considered, such as load factors, energy consumption from cooling units, fuel and electricity production and vessel operating speed. The report found that the main factor affecting emissions were the service speed of the vessel used in the intermodal chain. By running at 18 knots instead of the faster service speed, emissions from the alternative sea routes would be reduced to a similar amount as the basic routing (Sandvik, 2005). The results of the study can be observed in figure 2. As we can see, the reduction of vessel speed has a major impact on emissions. The lowest emissions are found on the route Trondheim-Kristiansand-Eemshaven with a Norwegian electricity mix. However, it is only marginally better than the base case via Oslo and Kiel.

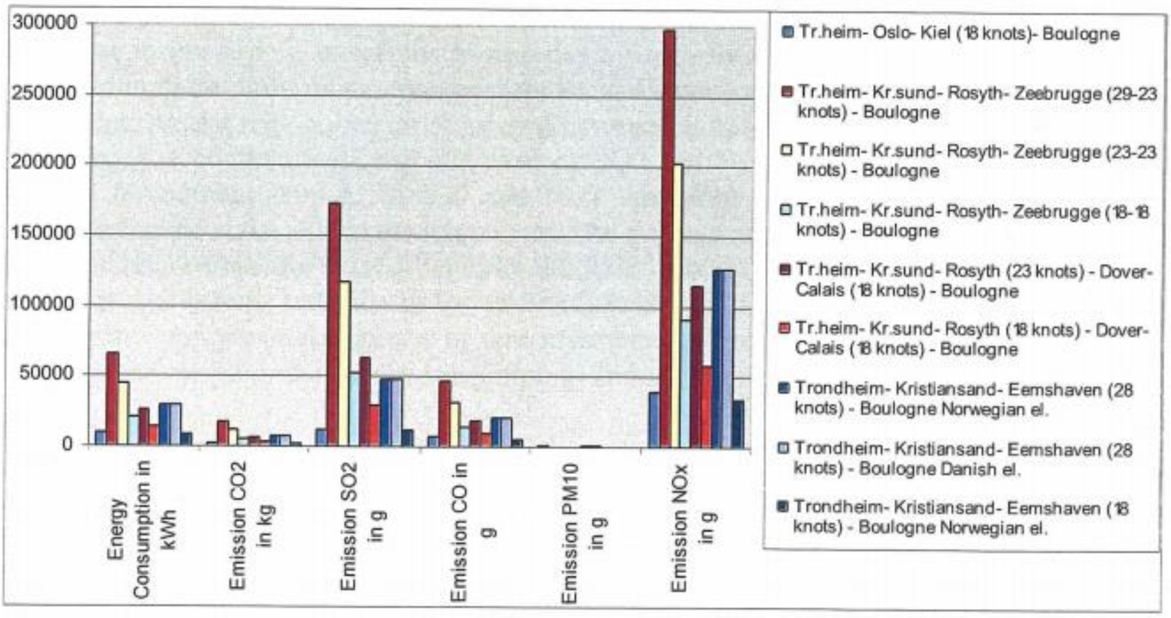


Figure 2: Energy consumption and emissions from all the alternatives from Trondheim to Boulogne (incl. production and transportation of fuel) per HGV (Sandvik, 2005).

The discussion of environmental sustainability by comparing transport modes is a well-documented topic, at least for shorter distances. Also, factors surrounding the emissions from different modes of transport have been observed for a longer period of time, which is also to be expected as fuel consumption is constantly changing because of more efficient engines, regulations concerning fuel, fuel prices etc.

Emission factors

Facanha and Horvath (2007) looked at emission factors from rail, air and truck throughout their life cycle.

Their analysis included the lifetime cycle emissions from not only the vehicles themselves, but also infrastructure and fuels. Regarding the vehicles, all emissions were included. From the vehicle manufacturing, maintenance and end of life, to petroleum exploration, refining and fuel distribution. The methodology used in the study was a hybrid Life-Cycle Assessment (LCA), combining a conventional process based LCA with an economic input-output analysis-based LCA. Their conclusion was that emissions from freight transport were underestimated if one looked only looked at tailpipe emissions. The findings were quite significant, with total life-cycle emissions from SO_2 and CO being up to seven times higher than tailpipe emissions. In a future perspective, new regulations are expected to significantly reduce the emissions of NO_x and SO_2 as these emissions are largely a result of fuel combustion. However, the same cannot be said about PM emissions as they are to a larger degree affected by other life-cycle phases (Facanha and Horvath, 2007).

Concerning emission factors for maritime transport, there is multiple papers covering this topic. However, there are differences how the factors are obtained. In a paper by Endresen et al. (2003), emission factors are based on a literature review where factors are obtained from multiple sources. These factors were presented as part of a bigger study where the impact of international sea transportation was examined. Using previous literature to establish emission factors was also done by Dalsøren et al. (2009). Like the study from Endresen et al. (2003), their study was also aimed at finding the impacts of international shipping emissions. Other studies have used different methods of establishing emission factors. In a paper by Eyring et al. (2005), the emission factors were calculated by dividing the total emissions from the maritime sector by the total fuel consumption. These emission factors were part of a study that was aimed at finding emissions from international shipping over the last 50 years.

The previous three papers have utilized a more “top-down” approach in which previous literature and statistics have been used to establish emission factors. In a paper by Corbett and W Koehler (2003), a different method has been used. In their study, information from engine manufacturers were used to calculate emission factors based on different engines and engine loads. In this study the aim was to find updated emission factors from shipping. What makes this study stand out compared to the others presented in this chapter, is that the emission factors presented are power-based instead of fuel-based.

Power-based emission factors tends to be based on g/kwh, compared to kg/ton fuel for fuel-based factors. Emission factors which are fuel-based tends to be flatter over the load range compared to power-based factors. However, the overall results tend to be similar regardless of which factors are used (Corbett and W Koehler, 2003).

3.2 External costs of transportation

In a broad sense an externality occurs when "*the consumption or production of one individual or firm has an unintended impact on the utility or production function of another individual firm*" (Mueller, 2003). For the transportation sector it will mean that through operations there will occur negative effects such as emissions to air, noise, water pollution, congestions and accidents that affect the surrounding areas that are not accounted for by the polluter.

Through the external effects, we get costs. When accidents occur, someone must pay for the damages, however who the bill goes to can be difficult to pinpoint because of the nature of externalities. An example of external costs can be a port where there is a large amount of emissions to air because of the operations there. People living in the vicinity can experience negative health effects because of these emissions, and consequently must pay more for healthcare services. The damages that occur are therefore external costs, i.e. not paid for by the person or institution causing the effects.

"Research interest in externalities of freight transportation has continuously expanded in the last decade due to the increasing impacts on economy, environment, climate and society" (Demir et al., 2015). Demir et al. (2015) clarifies how case studies dominates as a research method when it comes to determining and comparing externalities of transportation. Also, because geographical difference has such a large impact on what affects the pricing of transportation externalities, comparisons between geographical areas are important.

To be able to assess and compare the external effects pertaining to transportation with each other and with costs, it is beneficial to transform them into a common monetary unit. By converting the external effects into monetary units, we get external costs.

Thus, *"an external cost arises, when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group"* (Bickel and Friedrich, 2004).

An important field of application mentioned by Bickel and Friedrich (2004) is the performance of "cost-benefit analysis for policies and measures that reduce environmental and health impacts." When new policies and regulations emerge that aims to reduce environmental pollution this generally leads to higher costs for industry and consumers. Thus, it is important to assess and, in some way, confirm that the benefits from new policies or regulations outweigh the costs. To calculate the avoided external costs, Bickel and Friedrich (2004) mentions two necessary scenarios: a baseline scenario, which describes a development without the implementation of the policies or regulations and a scenario including it. By calculating these two, monetizing them and putting them up against each other the benefits can be compared with the costs.

The transportation sector contributes to emissions of airborne pollutants, noise and accidents, all of which can be categorized as external costs (Mellin et al., 2013). Naturally, the components of external costs will vary depending on mode of transport. Within the different modes of transport, there will also be differences in costs depending on factors such as route, type of vehicle and operating speed. In general, road transport has higher external costs than an intermodal setup (Ricci and Black, 2005, Kreutzberger et al., 2003). Because of this, policy makers are eager to shift more cargo from road to intermodal setups such as rail and sea (European Commission, 2011). One way of doing this is by internalizing external costs. This can be achieved by e.g. introducing fuel taxes and congestion charges which can target externalities related to climate change and road congestion (European Commission, 2013). While dependent on many factors, internalization of external costs has shown to encourage a shift to intermodal transport (Ricci and Black, 2005).

Sen et al. (2010) provides a methodology for estimating the marginal external costs of congestion, air pollution, road accidents and noise. For the marginal external pollution costs, they focus on the importance of four steps that can be indicative for other studies as well. These are:

1. Calculation of the emission caused by an additional vehicle km.
2. Calculating ambient concentration of major air pollutants due to vehicular emission.
3. Effects of air pollutants on, materials, health, visibility, eco-system, climate change etc.
4. Assign a monetary value to the different effects of air pollution.

Furthermore, Sen et al. (2010) elaborates on the importance of weighting the pollutants by severity along with constant emission factors for different vehicle types in different markets. This is a case for Delhi, India where the authors conclude that motor vehicles impose a large social cost and that to reduce pollution improved vehicle standards, better technology, fuel types and modal shifts to metro rail must be implemented.

3.3 Environmental impacts of transportation

The environment and transportation are two topics that often go hand in hand because of the sheer size that the transportation sector has become, and because of its proven effects on the environment. Especially global warming and health issues connected with air pollutants have been the focus concerning this topic, which is why we are covering this in our thesis. Thus, we will in this first section cover relevant science on the environmental impacts of transportation and theory on the four major types of air pollutants.

The issue of transportation and environment is paradoxical according to Rodrigue (2017) because it "*conveys substantial socioeconomic benefits, but at the same time impacting the environmental systems"*. Transportation supports the ever-increasing demand both for passenger-transport and freight, but at the same time it is the reason for growing levels of environmental externalities. The impacts on the environment is divided into three categories by Rodrigue (2017):

- **Direct impacts.** Where the results of transport activities can be directly linked to effects on the environment. Examples of types of emissions that have direct impacts are noise and carbon monoxide (CO).

- **Indirect impacts.** The indirect impacts generally have a higher consequence than direct impacts but they are harder to establish as they can be a result of several contributions. Rodrigue (2017) mentions that for instance particulates which are mostly the outcome of incomplete combustion in an internal combustion engine, can be indirectly linked to respiratory and cardiovascular problems. However, they only contribute to these among other factors, which makes them hard to pinpoint.
- **Cumulative impacts.** *"The additive, multiplicative or synergetic consequences of transport activities"* (Rodrigue, 2017). These are the varied effects of both direct and indirect impacts that transportation and their emissions have on the ecosystem. The main example here is climate change where CO_2 is the main benefactor. In this case, the transportation sector accounts for 15 percent of these emissions.

The transportation sector is constantly under surveillance when it comes to emissions and how it impacts the environment. Policy makers strive to implement regulations that intend to lower emissions from the different sectors to make transportation more sustainable.
An example of this is the International Maritime Organization (IMO) that is implementing a regulation in 2020 to limit the sulfur content in all marine fuels to 0,5 percent, from 3,5% today (IMO, 2019).

3.3.1 Emissions to air in transportation

"*Transport is a source of many harmful gases, and is one of the major contributors of several atmospheric pollutants"* (Button, 2010). We will look at four of the major pollutants that are connected to transport: PM, CO_2, NO_x and SO_2. Furthermore, we will connect these to the different modes of transport and find out which one has the most impact on the environment.

Carbon Dioxide

CO_2 is probably the most known, and talked about, pollutant because of its contribution to global warming. Button (2010) mentions that industrialized countries as a whole were responsible for 80% of CO_2 emissions (2000).
As for transportation, 26% of emissions of CO_2 are connected with this sector, constituting the second biggest polluter in the EU (Nocera and Cavallaro, 2011). With the transport sector's expected growth, emissions will continue to grow if no regulations or preventive methods are implemented.

However, because CO_2 can be found naturally in the air, even though it is miniscule, it is not strictly a pollutant. Excessive amounts have not been proven to have detrimental effect on human health but is widely known to be a contributor to global warming because it prevents heat from leaving the earth (Button, 2010).

Nitrogen Oxide

Nitrogen oxide (NO) and nitrogen dioxide (NO_2) is collectively referred to as NO_x. Because of the detrimental effects of NO_x on both the environment and health, the emissions from combustion sources have faced many regulations (Bowman, 1992). Approximately 50 percent of NO_x emissions stem from the transport sector (Button, 2010). Even though these numbers are from 2000, the transport sector still has the largest share of NO_x emissions (Qu et al., 2016). It plays a significant role as a component of acid rain when it is combined with SO_x which is damaging to the ecosystem.

"*The principal sources of nitrogen dioxide are traffic and to a lesser extent industry, shipping and households" (World Health Organization, 2006)*. High NO_x levels combined with other PMs and oxidants have become a major problem for urban areas around the world because of the health problems connected to this pollutant. NO_x exists as a gas and is therefore exposed to humans through inhalation. This can be troublesome as many can be exposed to the gas without knowing, even though it has a characteristic pungent odor.

Sulfur Dioxide

SO_2 is the main contributor to acid rain in conjunction with NO_x. Transport as of year 2000 had five percent of global SO_2 emissions. Diesel contains more SO_2 per liter than gasoline (Button, 2010). Coal-fired electricity generation is also a major source of this gas. Large urban areas have been heavily affected by both SO_2 and PM emissions because of poorly controlled combustion in industrial installations and coal used for domestic heating (World Health Organization, 2006). It is a colorless gas, but like NO_x, it has a pungent odor.

The IMO has been monitoring the sulfur levels especially in maritime vessels as they have been a large polluting factor. The sulfur levels allowed in current vessels lie at 3,5 percent, and by 2020 this will go down to 0,5 percent.

Because of the nature of both SO_x and NO_x, and the fact that 70 percent of emissions occur within 400km's of land, chronic exposure to shipping-related emissions account for 400 thousand premature deaths each year from lung cancer and cardiovascular disease (Sofiev et al., 2018).

Particulate Matters

PM pertain to the invisible, smell-less and tasteless types of emissions that can penetrate the body and cause illness, especially to the lungs. PMs are heavily connected to the combustion in diesel engines used for transport.

According to McCubbin and Delucchi (1999), PM is the most dangerous pollutant because of its complexity. "*It is a heterogenous mix of solid or liquid compounds, including aerosols, sulphates, nitrates, and metals suspended in the atmosphere"*. One of the complexities is size. For example, there is a difference in size of PM from diesel engines which are substantially different from the ones pertaining from road dust. Regarding shipping, around 95% of the PM pertaining to urbanized ports from ship emissions, falls under the category of $PM_{2,5}$ because of its aerodynamic diameter being less than 2,5μm (Tzannatos, 2010).

3.3.2 Impacts on the ecosystem

Ecosystems react differently to the different types of pollutants dependent on the areas of emission. For this chapter CO_2 will not be included as it affects the climate on a global scale through global warming and does not have any concrete impacts on specific areas. On the other hand, we have the noxious gases that can have detrimental effects on ecosystems.

Anthropogenic NO_x and SO_2 emissions, which is a denomination of emissions that is manmade, has been dramatically altering the global budgets. Globally, fossil fuel combustion has been releasing emissions into the atmosphere at a high rate. After chemical transformation in the atmosphere, much of the anthropogenic SO_2 and NO_x comes down as acids which dissociates in water (Doney et al., 2007). Because these noxious gases go into the atmosphere they go through acidification of both terrestrial and freshwater ecosystems by dry deposition and acidic rainfall which is a well-known problem for ecosystems such as coral reefs (Doney et al., 2007).

There are also several environmental issues caused by or in relation to the production, transformation and use of energy. Rosen and Dincer (2001) presents several examples such as water pollution, maritime pollution, land use and siting impact, hazardous air pollution and global climate change. The relatively low cost of fossil fuels has made it easy for humans to become reliant on them and has caused significant pollution which is endangering the planet's ecological diversity. Another significant emission mentioned by Rosen and Dincer (2001) is waste heat as this type of emission can alter the temperature of portions of the environment. Thermal pollution, if not controlled, can result in an imbalance of temperatures on local areas which in return can disrupt marine life and ecological balances in lakes and rivers.

On the effects on ecosystems, acid rain has been a thoroughly documented topic as this is a result of the combination of NO_x and SO_2 that goes up in the atmosphere and comes down as acid rain. Oceans and rivers are also not the only areas affected by acid rain.
Burns et al. (2016) mentions both surface-water acidification which is harmful for fish populations and forest soil acidification. Coal-fired power plants and emissions from combustion engines has environmental effects such as the acidification of surface waters and toxic effects on fish, vegetation and other biota. Acid rain has also been shown to impact cultural resources by accelerating the weathering of buildings and outdoor sculptures.

3.3.3 Impacts on human health

The impacts different pollutants have on human health varies significantly. Of the four pollutants in the comparison, CO_2 can be classified as the least damaging for human health (Button, 2010). As mentioned previously, CO_2 is primarily a concern regarding climate change and global warming. As such, it will have limited relevance regarding health effects of airborne pollutants. NO_x, however, is classified as a toxic gas. Because of its low water solubility, NO_x can more readily penetrate airways (Sperber, 2012). Short-term increases in NO_x have been associated with increases in respiratory-related hospital admissions and ED visits. Exposure to NO_x have also been proven to worsen the effects of asthma on children (Environmental Protection Agency, 2016). The release of NO_x causes the creation of ozone when NO_x is exposed to sunlight (Poupkou et al., 2008).

Ozone can cause symptoms such as cough, airway hyperactivity and lung inflammation (Uysal and Schapira, 2003). In addition to NO_x, SO_2 is also a pollutant with multiple documented negative health effects. SO_2 has been proven to cause acute respiratory health effects such as cough and decreased lung function. When exposed to high concentrations, SO_2 can lead to serious airway injury. While effects of controlled human exposure are clear on the negative impacts of SO_2 on human health, the effects of ambient levels of SO_2 over prolonged periods are not well defined (Chen et al., 2007). The final pollutant is PM. There have been several studies which aims to find the health effects of exposure to PM. Measuring PM and finding correlation between exposure to PM and health effects on humans is difficult. Nonetheless, studies have shown that short term exposure to PM does not have significant negative health effects (Pope III and Dockery, 2006). However, long term exposure has shown to cause chronic health effects. These health effects are for the most part related to cardiovascular disease and lung cancer (Pope III and Dockery, 2006).

3.4 Modes of transportation

We have four types of transportation that is used for both freight and passenger transport. These come with different strengths and weaknesses that dictates where the mode is more dominant than the other. Also, when it comes to emissions these modes vary both in emission types and scope. We will therefore address each mode to give the reader an overview of the different modes.

3.4.1 Air

For short delivery times and an overall edge in speed, air freight transport is used for the smaller cargo that holds a lot of value or is perishable. According to International Air Transport Association (IATA), the value of goods transported by air exceeded $6.2 trillion in 2018. However, even though airlines transport more than 52 million metric tons of goods per year, this only accounts to 1 percent of world trade by volume (Merkert et al., 2017). Cargo with high value or low shelf life can be jewelry, phones, flowers, medicines, etc. For regular passenger airlines, cargo accounts for less than 5 percent of total revenues (Rodrigue, 2017). Furthermore, when it comes to the emissions from air freight transport, Brueckner and Abreu (2017) mentions the fact that even though the CO_2 emissions from the industry only accounts to 2,5 percent of total emissions as of 2006, the impact per kilogram is double that of ground-level emissions because of the high altitude of the emissions.

The result is a high climate effect on top of the already high emissions per ton-km, as illustrated by McKinnon (2004) in figure 3.

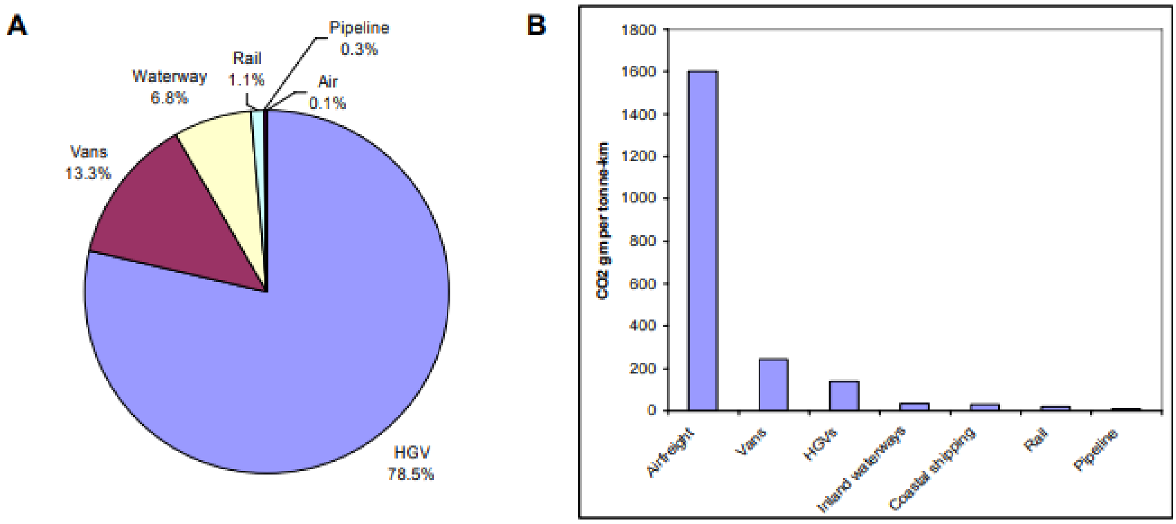


Figure 3: Modal shares of CO2 emissions and CO2 per ton-km values for UK domestic Freight Transport (2004). Figure obtained from McKinnon (2004)

3.4.2 Maritime transport

The most dominant mode of transport when it comes to tonnage moved is found through maritime transport. One of the reasons is that the capacity of vessels is so high that the whole operation benefits from economies of scale. Furthermore, containerized shipping is relevant because of the fact that 60 percent of the value of goods transported by sea comes from general cargo which is mostly containerized (Stopford, 2009). Transportation of containerized goods is also known as a liner service which means that the transport is frequent and reliable for almost any kind of cargo that can fit in a container. Compared to other modes, liner shipping benefits from low unit costs because of the capacity of the vessels. However, with such large operations comes emissions.

Oceangoing ships account for approximately 15 percent and 13 percent of global anthropogenic NO_x and SO_x emissions, respectively and approximately 2,5 percent of global CO2 emissions (IMO, 2014, Fan et al., 2018). Eyring et al. (2005) mentions that 70 percent of ship emissions occur within 400km of land, which can have negative effects on health and ecosystems.

Shipping emissions consist of many different pollutants. In this paper, CO_2, SO_2, NO_x and PM are the most relevant.

CO_2 emissions is to a large degree a global problem rather than a local one as it contributes to global warming (Button, 2010). In the broader picture, the CO_2 emissions from shipping is much lower than it is for road transport by a significant margin (Fuglestvedt et al., 2008). Regarding SO_2, the contribution from shipping is much more dominant and it is the mode of transport that has the highest emissions of this substance. The effects from SO_2 are several. In a global warming perspective, SO_2 contributes to the cooling of the planet. Combined with NO_x emissions, the shipping sector is a net contributor to global cooling in the short term (Fuglestvedt et al., 2008). Though shipping is not the worst performer if we look at global warming, it does emit pollutants that are negative for ecosystems and human health. SO_2 and NO_x are pollutants which is harmful to the environment and which can be transported far away from its source (Eyring et al., 2010).

One of the reasons why the shipping sector is emitting such a relatively high amount of SO_2 is because of the fuel being used. A large part of the world fleet uses HFO with a high sulfur content (2,4-2,7%). In the coming years, we can expect SO_2 emissions to be reduced as new IMO regulations comes into force in 2020, limiting the maximum sulfur content in fuel to 0,5%. This will be an important step towards mitigating the negative health effects caused by SO_2. A report by the IMO concluded that the implementation of a lower sulfur limit in fuels in 2020 would reduce the amount of premature deaths caused by SO_2 by 570 000 worldwide during a 5 year period (IMO, 2019). However, as of today the new regulations have not come into force and emissions from SO_2 remains a large problem. SO_2 and NO_x have been proven to contribute to increased acidification of the ocean, with coastal areas being especially exposed. An increase in acidification is a major threat to ecosystems, such as coastal benthic and planktonic food-webs and coral reefs due to calcifying of organisms (Doney et al., 2007). While local effects of SO_2 and NO_x are not preferable, the cooling effect these substances have can to some degree be beneficial according to some academics.

In a global perspective, a reduction of HFO sulfur content can increase global warming since the cooling effects of SO_2 and NO_x are mitigated (Lindstad et al., 2015). The impact of shipping can clearly be seen in figure 4. As we can observe, emissions of NO_x and NO_2 is visible on satellite measurements.

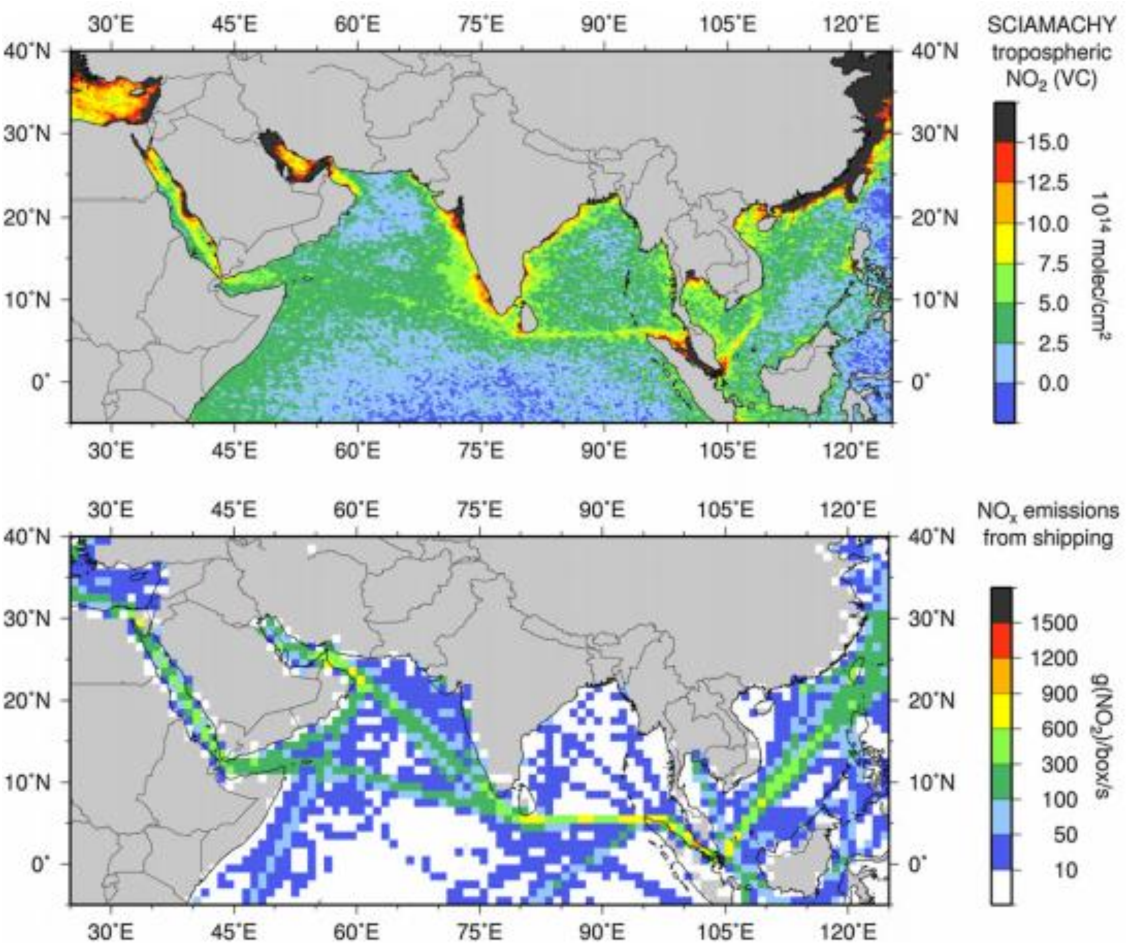


Figure 4: NO_x signature of shipping in the Indian Ocean. Figure obtained from Richter et al. (2004).

For harbor cities, emissions from ships are often a dominant source of increased urban pollution (Cofala et al., 2007). While shipping emissions are often released away from land, airborne pollutants can travel long distances and affect ecosystems on land. As mentioned previously, one concern is sulfur and nitrogen compounds which cause acidification of natural ecosystems and freshwater bodies. This can pose a major threat to biodiversity through excessive nitrogen output (Cofala et al., 2007).

3.4.3 Land

Road

Road transport is almost exclusively provided by trucks. The largest benefits of road transport are the flexibility it offers. Trucks can carry almost any type of cargo over short to medium distances, from specialized cargo to standardized containers (Rodrigue, 2017). In addition to the flexibility, trucks have low capital costs, allowing new users to enter the market with relative ease. This leads to a highly competitive market and lower prices.

Compared to other modes of transport, trucks offer fast transit times, with the only major constraint being local speed limits. Finally, the road network allows for flexible routing, making road transport a viable choice for door-to-door transportation (Rodrigue, 2017).

One of the main characteristics of road transport is that it relies on a road network that in most cases are offered by the government. In fact, as much as 95% of road infrastructure is financed by the public sector, with the remainder being covered by road tolls (Rodrigue, 2017). While good for the private sector, it leaves some problems unanswered. Roads in urban areas tend to be congested, with users having limited possibility to mitigate the problem by increasing capacity. In addition, the funding of roads is often lackluster due to the high cost of maintaining the road network. Since roads are a public good, the users of the roads do not pay for the full cost of using them. This means that road transportation is to some degree subsidized and that the real market price is not paid (Rodrigue, 2017).

Road transportation has a major disadvantage when it comes to the environment and especially CO_2 emissions. As shown in figure 5, road transport has had a growth in CO_2 emissions far greater than other modes of transport. Road transport is responsible for 72% of the CO_2 emissions related to transport and 17% of the total global emissions (Uherek et al., 2010).

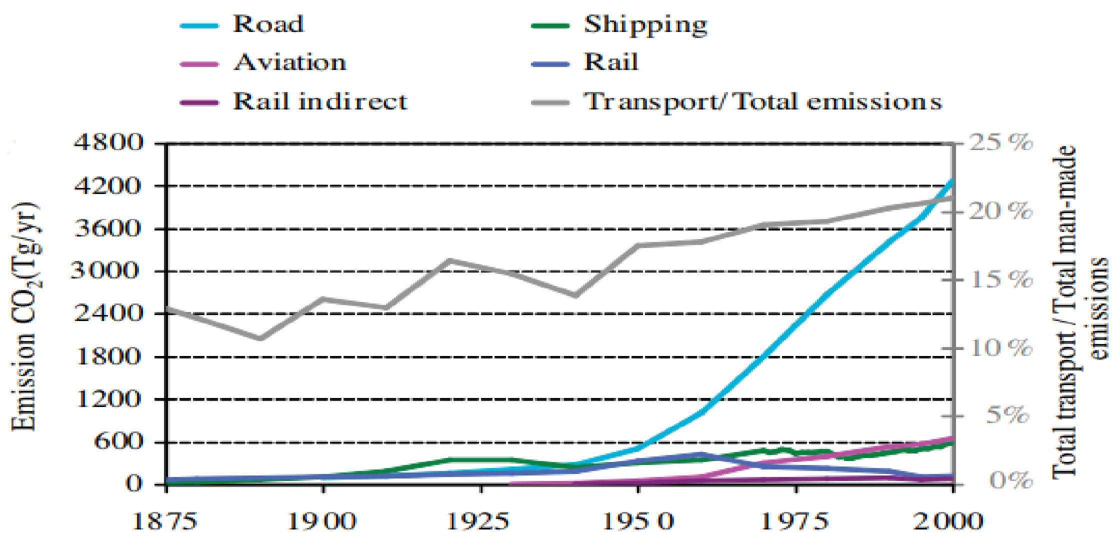


Figure 5: Development in CO_2 emissions from the various transport subsectors and the fraction (right axis) of total man-made CO_2 emissions (excluding land use charges). Figure obtained from Fuglestvedt et al. (2008).

Rail

Transportation by rail is categorized by its ability to transport large quantities of goods over long distances. Railways lack the flexibility of road as railway infrastructure is not as widespread and it relies to a large degree on scheduled services. However, the cost advantage against road can prove to be significant as railways can utilize a higher degree of economies of scale. The capacity per train depends on region and varies from 600 TEU's in the United States to 80 TEU's in Europe. This is due to differences in infrastructure and train wagons. In the United States, it is common to "double-stack" containers on railway wagons to further increase their utility. Also, the infrastructure is more recent and focused on the freight market as opposed to the passenger market which is the case in Europe. Due to these factors, railways have a higher modal share in the United States compared to Europe (Furtado, 2013). Against road, railways are more cost effective once the distance travelled exceeds 950-1300 kilometers. At shorter distances the cost of drayage, i.e. moving goods to and from an intermodal terminal, becomes too high for rail to be a viable alternative (Rodrigue, 2017). Compared to road, the rail freight market is not very competitive and is often categorized by monopolies or oligopoly. This is due to the high capital costs of rail and that railways often are regulated monopolies. The rolling stock and infrastructure is very capital intensive, with 17% of revenues being put into capital expenditure, compared to 3-4% for the manufacturing sector (Rodrigue, 2017). Moving further ahead, railways are continuously being updated with electrification of lines and increased automation. These developments further increase the efficiency of rail transport. As of today, rail freight is between 1,9 to 5,5 times as energy efficient as road transport (Rodrigue, 2017).

The strong environmental performance of rail is further visualized by looking at the sectors emissions compared to other modes. In the EU, rail accounts for 0,6% of transport's GHG emissions through direct usage (diesel), and 1,5% if electricity generation is taken into account (CER/UIC, 2015). As we can observe from figure 6, rail transportation has CO_2 emissions that are lower than both inland shipping and truck by quite a significant margin. Between 1990 and 2010, emissions per ton-km from the European railway sector was reduced by 41%. The goal of the sector is to have carbon-free train operations by 2050 (CER/UIC, 2015).

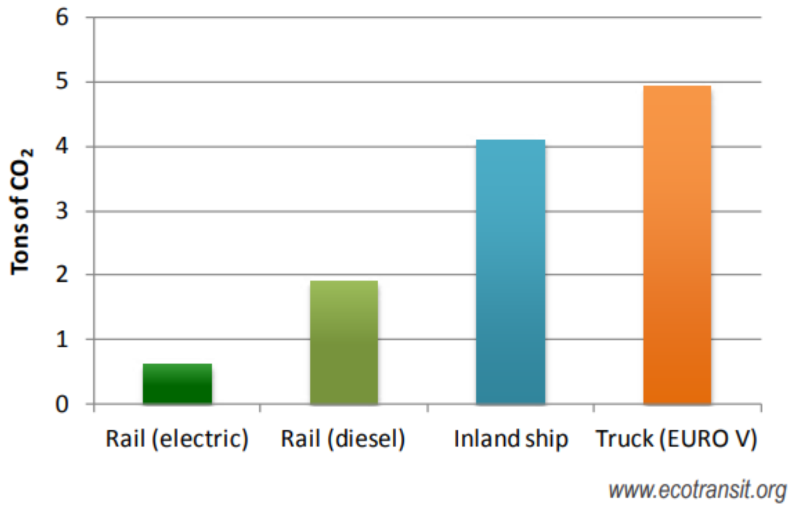


Figure 6: Comparison of CO_2 emissions/100 tons between different modes of transport on the route Basel, Switzerland to Rotterdam, The Netherlands. Figure obtained from CER/UIC (2015).

3.4.4 Intermodal

With the growth of containerization in the 1960's, it became possible to combine two or more modes of transport with greater ease. Rodrigue (2017) defines intermodal transport as *"the use of at least two different modes in a trip from an origin to a destination through an intermodal transport chain"*. In practice, this means that a customer can order transport from one point to another using a single bill of lading despite multiple modes of transport being used.

An intermodal transport chain consists of four major functions as described by Rodrigue (2017):

- **Composition.** Often referred to as the "first mile". During this function cargo is consolidated at a freight terminal which offers an intermodal interface between a local/regional distribution system and a national/international distribution system. Usually cargo arrives at the terminal with trucks.
- **Connection (transfer).** The transfer of cargo usually involves rail, containership or a fleet of trucks between at least two terminals over a national or international distribution system. How efficient the connection is will depend on economies of scale (e.g. large containerships, double-stacking) and frequency of service.
- **Interchange.** The interchange takes place in the realm of national and international freight distribution systems. In this function freight gets transferred at transshipment hubs where the goal is to ensure continuity in the intermodal chain.

- **Decomposition.** Often referred to as the “last mile”. When cargo arrives at a terminal close to its destination, cargo is fragmented and distributed to the final customer.

One of the key benefits of intermodal transport is the ability to utilize different modes of transport to its full extent. For example, by using rail or ship for long distances and trucks for final distribution. The type and value of the cargo is to a large degree what determines the attractiveness of an intermodal solution. Generally, medium value intermediate and finished goods are seen as typical cargoes for intermodal transportation (Rodrigue, 2017). Intermodal transport is also seen as favorable for those customers who value a lower environmental footprint. Compared to trucking, intermodal transport has significantly lower CO_2 emissions (Craig et al., 2013).

3.5 Transportation across borders

International transportation works as a fundamental element supporting the global economy. As about half of the global trade takes place between locations more than 3000km apart, cross-border transportation cannot be avoided (Rodrigue, 2017). China, and Pacific Asia has been dominating factors behind the growth of international trade because of their economic development in recent years.

These developments have been noticed by increased maritime activity because of the many rivers connecting Chinese provinces. An example is the Pearl River Delta in Guangdong that now handles as many containers as all the ports in the United States combined (Rodrigue, 2017).

Geography and geopolitical considerations are interesting themes when talking about transportation as many countries can be connected to a trade route. Strategic locations have therefore been sought after by countries to gain advantages when it comes to trade. Rodrigue (2017) considers five perspectives of the geopolitics of international trade:

Conquest. Developing technology to control and conquer oceans, territory and resources. This was mostly during a period of early globalization to access and control markets.
Competition. *“International transportation is a means of competing on the global economy.”* Competition has been shaping the modern transportation systems as countries develop their own international systems to be competitive.

Jurisdiction. A big part of international trade is the jurisdiction that all sovereign nations have over their territories. Any international transport entering, exiting or going through territories are subject to national regulations. Bad relations between nations can therefore have heavy impacts on trade routes where both are involved.
Cooperation. Even though competition is heavily involved in international transportation, cooperation is also sought after to open the possibilities for good trades. An example here is the rail gauge standard (1,435mm) which means that the railway operates with the same type of rails throughout the route, which can be a quite severe constraint if it is not standardized. This becomes a problem when traveling through countries such as Russia where they have a different standard to their rail gauge (1,520mm). With the development of the New Eurasian Land Bridge, collaboration between the countries involved has been engaged by China in particular. For example, by investing in terminals along the way.
Security. As the global economy becomes more interdependent, vulnerability to supplies of raw materials, energy and food can be damaging to the economy.

3.5.1 The Belt and Road Initiative

As this paper focuses on the transport of containerized products between China and Norway, and the emissions connected, it will be of great interest to look at the new proposed trading routes currently in the works under the name "Belt and Road Initiative".

Maritime container transport between Europe and East Asia typically uses hub ports in Northwestern Europe where the cargo is transshipped to the end customer around Europe. With the Belt and Road Initiative, China aims to transform several routes into modernized silk roads both for maritime transport and rail known as "Silk Road Economic Belt" and a "21st Century Maritime Silk Road" (Yang et al., 2018). This initiative has launched massive investments into infrastructure to realize this goal. As of April 2018, eighteen Chinese cities have opened direct railroad container services to European cities (Yang et al., 2018).

3.5.2 Corridors

Figure 7: Railways and sea corridor from China to Norway.

In figure 7 the railways and sea corridor is presented.

- **New Eurasia Land Bridge.** Connecting China with Europe via rail through Kazakhstan and Russia.
- **Trans-Siberian.** Running more north than the previously mentioned corridor, it can be an alternative routing. This corridor passes through Mongolia.
- **Zhengzhou-Qingdao-Hamburg-Oslo.** Sea corridor running further south than the railway alternatives. Standard routing for most China-Europe goods today.

3.6 China-Norway trade

Trade between China and Norway stood at around 92 Billion Norwegian Kroner (NOK) for the year 2018, in which Chinese exports to Norway accounted for 71,3 Billion NOK as seen in figure 8. Using the Standard International Trade Classification (SITC), the largest groups of products exported from China to Norway were machinery and transport equipment, miscellaneous manufactured articles and manufactured goods classified chiefly by material. Norwegian exports to China stood at approximately 20,7 Billion NOK for the year 2018, with the largest product groups being chemicals and related products, machinery and transport equipment and food and live animals (Statistics Norway, 2019).

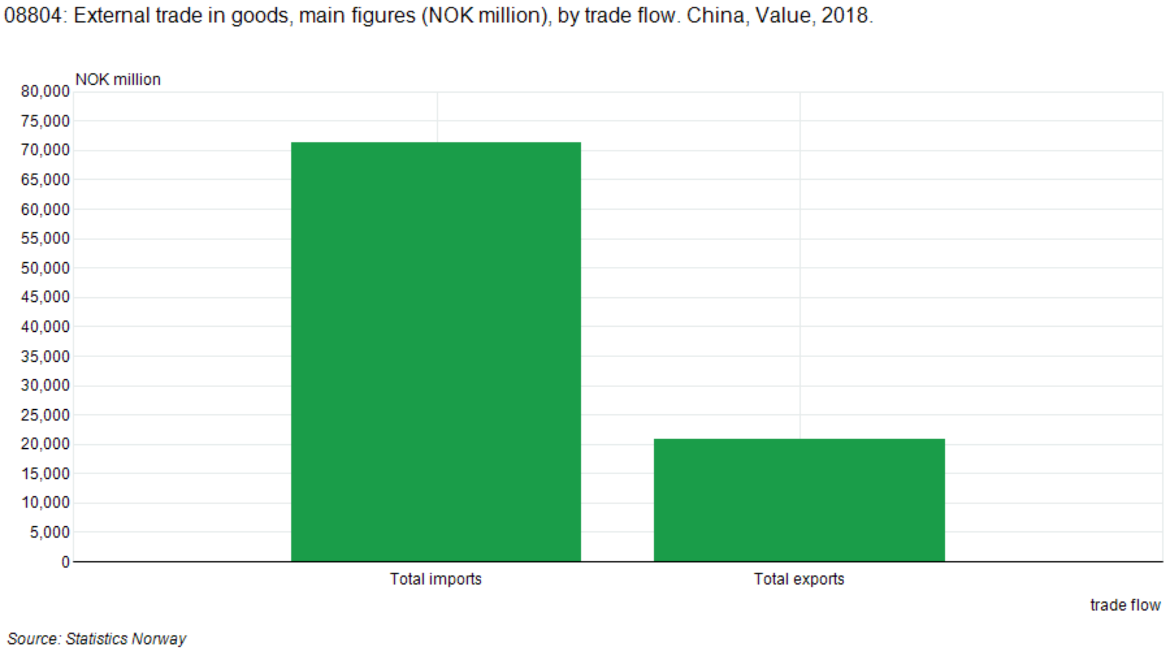


Figure 8: Trade flows in goods between Norway and China in year 2018.

Trade between Norway and China is skewed in China's favor, with China having a trade surplus of 50,5 billion NOK. For Norway, China is the third largest import partner behind Sweden and Germany (Statistics Norway, 2019).

3.6.1 Container trade volumes

Our first research question concerning the trade volumes of containers from China to Europe is aimed at giving an overview of how large this operation is, and why this trade corridor is relevant when comparing and assessing the environmental impacts between the different modes. Most of the trade volume is shipped by sea because of the unmatched economies of scale compared to any other mode. In total, container sea trade from China to the EU totaled 16,44 million TEU's in 2017 (Eurostat, 2019). How much of this figure is further exported to Norway is unknown. For the new railway alternative, the same figure was between 275 and 280 thousand TEU's in 2018. A figure that is expecting to rise to 350 thousand in 2019 according to the United Transport and Logistics company – Eurasian Railway Alliance (UTLC ERA, 2018).

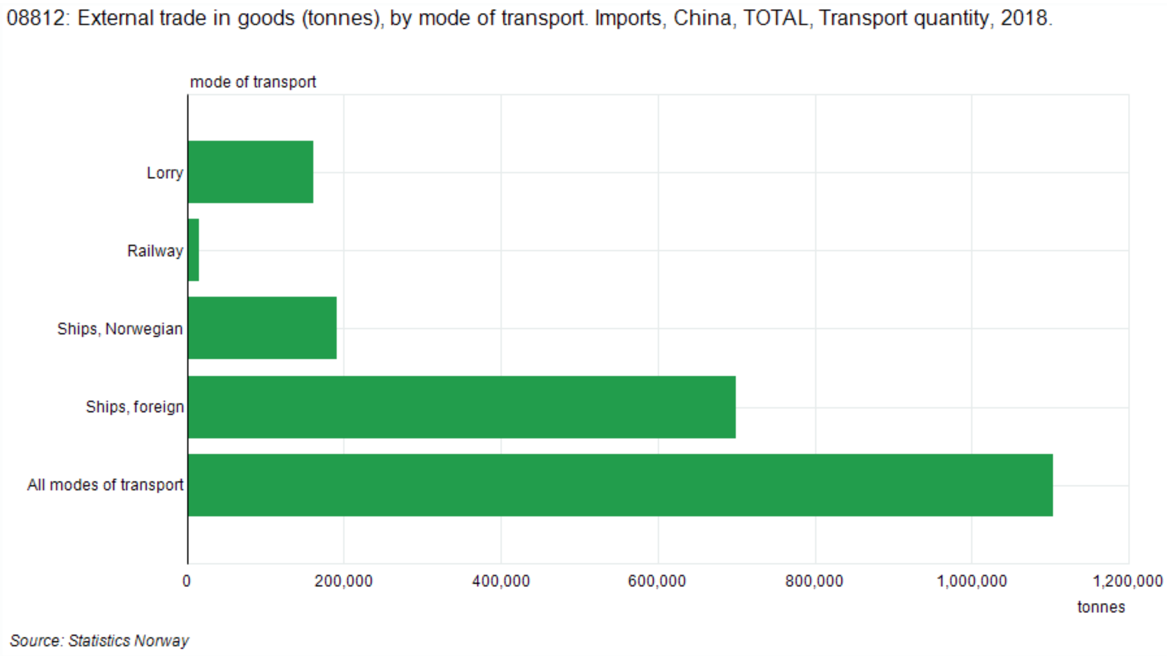


Figure 9: Import of goods from China to Norway in tons for the year 2018 (Statistics Norway, 2019).

In 2018, around 1,1 million tons of goods were imported from China to Norway. The modal split of these imports is visualized in figure 9. As we can observe, most goods arrive via ship. Only a very small amount arrives via railway. However, there are some uncertainties as these figures only show the mode which was used when crossing the border into Norway. Due to the use of intermodal setups, the mode used for the long haul from China to Europe might differ from these figures. This is because much of the cargo from China gets transshipped somewhere else in Europe before it arrives in Norway. There is also some uncertainty regarding how much of this trade arrives in containers as opposed to bulk.

3.6.2 2010 Nobel Peace Prize

After the Nobel Peace Prize was awarded to the Chinese dissident Liu Xiaobo in 2010, China reacted harshly and relations between Norway and China became sour. China snubbed Norwegian ministers, suspended free-trade talks and denied shipments of farmed salmon from Norway (The Economist, 2012). Exports of Norwegian salmon got hit hard by new "quality controls" at the Chinese border in the wake of the prize, with salmon being stuck at the border until it spoiled. As a result, salmon exports to China in 2011 was at 30 percent of the 2010 level (Luttwak, 2012).

Though the sanctions were noticeable, they were short lived and exports to China were back to normal in 2014. Despite there being no normalization of diplomatic relations at that point, the normalization appears to have been a result of the Norwegian government trading concessions on human rights for resumed trade access to the Chinese market (Kolstad, 2016). Sverdrup-Thygeson (2015) mention that trade between the two countries remained relatively undisturbed, but that there are reasons to believe that trade would be even larger if sanctions were not put in place.

3.6.3 Normalization of relations

After 6 years of diplomatic freeze between Norway and China, normal relations were restored in late 2016. The normalization of relations is expected to increase trade by significant amounts. Salmon alone could see a twentyfold increase in exports (Milne, 2016). As of today, Norway and China are working on finalizing a free trade agreement which will further boost trade between the two countries. A feasibility study concluded that a free trade agreement would: *"promote the economic development of China and Norway, as a result of productivity improvements linked to increasing competition and opportunities to exploit economies of scale in the larger market, and re-allocation of resources between industries associated with increasing product specialization in line with comparative advantage."*(Norwegian Ministry of Trade and Industry, 2008).

3.7 Summary of chapter

Previous papers on the topic of emission-comparisons between modes are dominated by emission factors and case comparisons. Relating to transport emissions are external costs. External costs can be defined as costs imposed on society which are generally not paid for by the user. These costs include damages on the environment, noise, accidents, congestion etc.

There are multiple modes of transportation available for the transportation of goods. These range from land-based modes such as road and rail, to sea and air transport. Transportation can also be done with multiple modes on one route, which is known as intermodal transport.

Today, much of the transportation takes place across borders due to an increase in world trade. China is further aiming at increasing trade via the OBOR initiative across Asia and Europe. Trade between Norway and China has been through a tough period after the Nobel Prize was awarded Liu Xiaobo in 2010. However, trade and relations have been normalized in later years.

4.0 Analysis

In the analysis chapter we will go through the different corridors, their characteristics, emissions and how the emissions affect the areas surrounding the corridors. The OBOR Initiative has not necessarily opened new corridors between China and Europe. However, because of the investments made primarily by China along these routes to make them more efficient, it has opened new possibilities for shippers that look for an alternative to sea transport.

Three corridors are of interest in this thesis. These are:

- The New Eurasian Land Bridge
- The Trans Mongolian/Siberian Railway
- Maritime route through the Suez Canal

We have decided to go with two railway routes and one maritime route. The two different railway corridors are interesting to compare because of their geographical differences. On the other hand, only one maritime corridor is of interest because alternative setups are too similar. These three routes also have a similarity with Hamburg working as a transshipment hub before the last leg towards Oslo.

4.1 General assumptions

For our comparison, we will assume the use of a standard forty-foot equivalent unit (FEU) container with a gross weight of roughly 25 tons. The reason for this choice is that it gives a realistic comparison as containers are used for both the sea and rail alternative in an intermodal setup.

To give a realistic case, we are assuming the cargo to be electronics as this cargo fits well with both alternatives, as well as the fact that the city of origin, Zhengzhou, is a major electronics manufacturing center (Barboza, 2016). The routes selected for the comparison is based on up to date timetables and realistic estimates. As for the railway alternative, it is based on scientific literature and EcotransIT.

For the calculations, we have decided to use Tank-to-Wheel (TTW) for all modes of transport that rely on fossil fuels. In the case of electrified railways, we have decided to use Well-to-Wheel (WTW). The reason for this choice is that to measure emissions from electrified railways, the origin of the electricity needs to be considered. To keep the comparison fair, the primary energy factor (PEF) of each country will be applied to the calculations. This will be further explained in a later chapter.

4.1.1 Sea route

Sea transportation from Qingdao to Hamburg are based on the French Asia Line 2 operated by COSCO Shipping in cooperation with CMA CGM on the route from Qingdao to Hamburg (CMA CGM). Further, from Hamburg to Oslo the route is based on Hamburg Norway Service 5 operated by United Feeder Service Ltd, also on behalf of CMA CGM (CMA CGM). As such, the calculations on this route will be based on vessels of the same size as the ones used on these two services.

4.1.2 Rail route

The different rail routes have a varying degree of electrification. As such, we will assume that all stretches of railway that are electrified is being run by electric locomotives. Also, that non-electrified railways are being run by diesel powered locomotives. The information regarding which stretches of railway are electrified are obtained from EcotransIT and an United Nations report (EcotransIT, 2019, UNESCAP, 2017).

4.2 Description of corridors

4.2.1 Sea route

The sea route and its different modes are presented in table 1.

Table 1: Route description sea route.

Route	Distance (Km)	Mode of transport
Zhengzhou – Qingdao	750	Truck
Qingdao – Hamburg	20 440	Deep sea container vessel
Hamburg - Oslo	830	Short sea container vessel
SUM	22020	

The route starts at Zhengzhou where containers are loaded on a truck bound for Qingdao. In Qingdao, containers are loaded onto a large container ship for its voyage to Europe. The sea route is visualized in figure 10. It goes along the coast of China along the East China Sea before entering the South China Sea. Further, it passes the Strait of Malacca into the Indian Ocean. Afterwards, it goes through the Gulf of Aden and the Red Sea where it enters the Suez Canal. Finally, it goes through the Mediterranean Sea, Gulf of Biscay and English Channel before entering the North Sea and Hamburg.

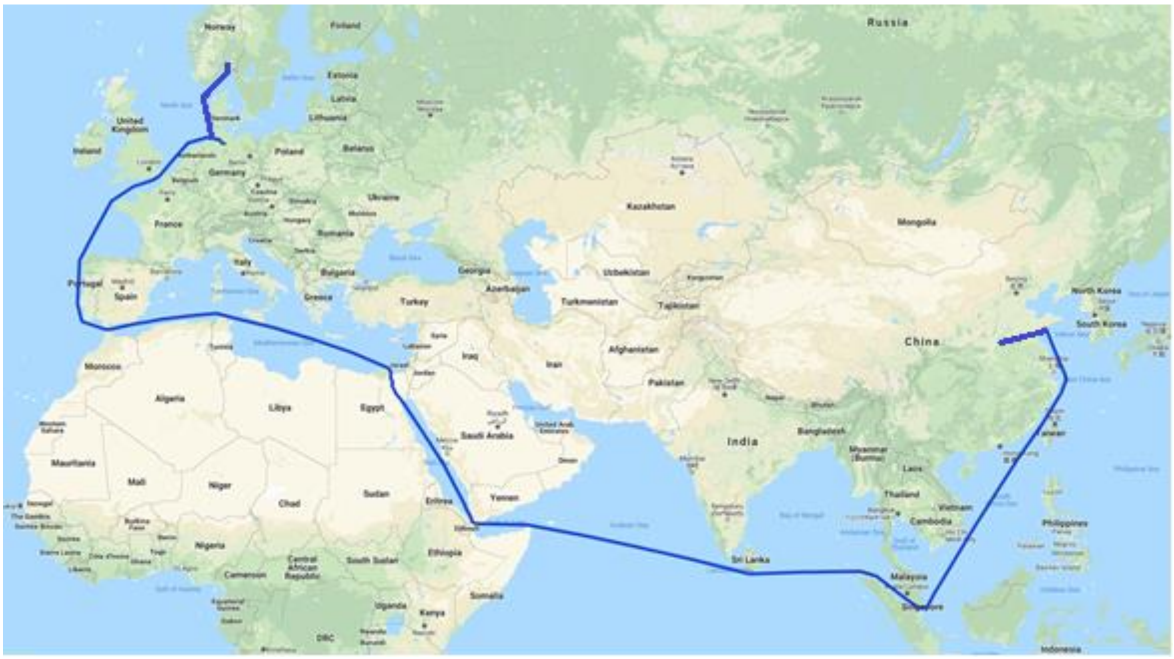


Figure 10: Sea route (EcotransIT, 2019)

Further, the vessel arrives in Hamburg, Germany where containers are loaded onto a smaller short sea container vessel bound for Oslo.

4.2.2 The New Eurasian Land Bridge

The route of the New Eurasian Land Bridge and its modes can be seen in table 2.

Table 2: New Eurasian Land Bridge route description.

Route	Distance (Km)	Mode of transport
Zhengzhou - Khorgas	3650	Train (electrified)
Khorgas - Almaty	310	Train (diesel)
Almaty - Małaszewicze	5145	Train (electrified)
Małaszewicze - Hamburg	1050	Train (electrified)
Hamburg - Oslo	1065	Truck
Sum	11220	

The New Eurasian Land Bridge is a railway route stretching 10 155 km across China, Kazakhstan, Russia, Belarus, Poland and Germany. It is the shortest and most widely used route along the OBOR due to its good infrastructure and short transit times (UIC, 2017). Along the route, the cargo must be transferred twice due to differences in railway gauges. This happens at the border in Kazakhstan and Poland. The railway line is primarily electrified, with an exception of a shorter stretch in Kazakhstan. From the start at Zhengzhou Putian railway station, it goes on the 3650-kilometer-long railway journey towards the Kazakh border. On this part of the route the locomotive is electric. At the Khorgas border crossing, containers are loaded onto a wider gauge train used in Russia and the former United Soviet Socialist Republics (USSR). The process of transshipping containers at Khorgos only takes 47 minutes and the train can continue on its journey shortly afterwards (UIC, 2017). Further, the train continues to Almaty on a diesel train. From Almaty the railways are electrified all the way to Hamburg going through Kazakhstan, Russia and Belarus on wider Russian gauges. At the Belarussian/Polish border crossing between Brest and Małaszewicze, containers are again transferred to European gauge wagons. The border crossing between Belarus and Poland has often been cited as a bottleneck along this route despite a capacity increase. As a result, some carriers are looking for alternative border crossings to further reduce transit time (Patzner and Barrow, 2018). The remainder of the rail route goes straight through Poland before arriving in Hamburg, Germany. In Hamburg, containers get loaded on trucks for the final trip to Oslo.

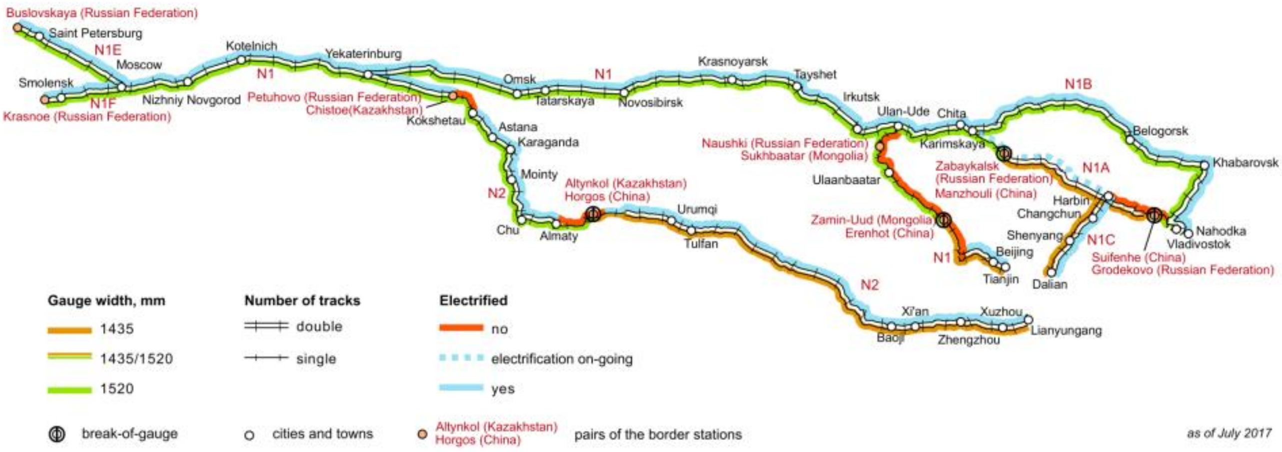
4.2.3 The Trans Mongolian/Siberian Railway

The Trans Mongolian/Siberian Railway corridor and modes that are being used is shown in table 3.

Table 3: Trans Mongolian/Siberian Railway route description.

Route	Distance (Km)	Mode of Transport
Zhengzhou - Datong	964	Train (electrified)
Datong - Ulan-Ude	1909	Train (diesel)
Ulan-Ude - Małaszewicze	6451	Train (electrified)
Małaszewicze - Hamburg	1051	Train (electrified)
Hamburg - Oslo	1065	Truck
Sum	11440	

The Trans Mongolian/Siberian Railway stretches across 10 375 kilometers and connects the Far East with Northern Europe through a railway system that has been in place for many years, and that in recent years have been further developed to be able to handle more cargo. The railway alternative is also divided into two types of fuel consumed along the route, diesel and electricity. Like the other railway alternative, the fact that different countries operate with different track gauges means that at two border crossings the cargo will have to be loaded onto a new train that can take it onwards. Zamin-Uud is the first location where the difference in track gauge leads to a change of train. From this point, as most of the railway goes through Russia, the need for changing gauges does not present itself before the train reaches Małaszewicze, Poland, which is the last stop before Hamburg.



Source: Varvara Krechetova.

Figure 11: Railway infrastructure along the Eurasian Northern Corridor. Figure obtained from UNESCAP (2017).

Zamin-Uud is located at the border between China and Mongolia and connects China to the rest of the trans-Siberian railway. At this point there is a change in track gauges to the wider Russian railway tracks. As shown in figure 11, China operates with a track gauge that is 1,435mm while Mongolia and Russia, that most of the route consists of, uses 1,520mm. This means that the dry port at Zamin-Uud works as the biggest and most strategically important port in terms of logistics on the southern border with the People's Republic of China (PRC) (Solongo, 2018). The railway terminal handled 850 million tons of cargo in 2015 and is expected to grow annually because of increased Asia-Europe trade. From Zamin-Uud the cargo is transported towards Ulaanbaatar which is the capital of Mongolia. "*85% of total export and import goods of Mongolia is concentrated in Ulaanbaatar city and transported by railway"* (Solongo, 2018).

Because of the rapid growth of cargo each year in this area, Ulaanbaatar has become a bottleneck for railway cargo. As a result, there are plans of building an international terminal that can handle the growing amounts of containers.

When it comes to the geographical location of the railway, 64% of the route goes through Russia while the rest of the route is spread between China, Mongolia, Belarus, Poland and Germany. What characterizes this corridor is that a major part of the route goes through the Siberian parts of Russia which are quite deserted, but with a fair number of smaller cities throughout. This route is also electrified except for Mongolia and parts of China where diesel is used.

4.3 Emission factors

In order to compare the different corridors, it is essential that we have emission factors that correspond with the aim of our thesis. We decided to find several papers on the topic of emissions to make sure that there is a consensus on the factors and that they have stayed approximately the same for several years. The papers are also from different years so we can see if there are any significant changes over time.

Furthermore, we have found numbers on fuel consumption for all three modes of transport with railway and maritime being the focus as these routes are the longest in the comparison. For maritime we found numbers were more readily available as this topic has been covered by many different scientific papers as well as government websites and books. Thorough research on this subject has given us indicative numbers pertaining to fuel consumptions for different sizes of ships as well as how fuel consumption exponentially grows with speed.

For railway, the numbers have been collected from EcotransIT, as very few papers cover the specific topic of air pollutants from railway freight. This is especially the case from China to Europe. Their methodology will be elaborated on in chapter 4.3.2.

4.3.1 Shipping

Emission factors in shipping can be seen in table 4. The figures presented are to a large degree consistent between the different studies which further enhances their validity. A noticeable exception is some of the figures presented by Endresen et al. (2003).

In their study, SO_2 emission factors includes distillate fuel in addition to residual fuel. Further, the figures for NO_x and PM includes medium and high-speed engines. For the sake of this study, the lower figures arising from the medium and high-speed engines will not be considered and the first number stated will be used. Regarding SO_2 emissions, the figures from distillate fuel can be relevant in the context of new IMO regulations as these require fuels with lower sulfur content.

Table 4: Emission factors of compounds emitted by diesel powered ships reported from different studies in Kg/ton fuel burnt. Table adopted and modified from Eyring et al. (2010).

Paper	CO2	SO2	NOx	PM
Dalsøren et. al (2009)	3179	54	89	7,6
Corbett and Koehler (2003)	3179	48	83	6
Endresen et. al (2003)	3170	54a/10b	87c/57d	7,6e/1,2f
Eyring et. al (2005)	2860	45	86	5,9

[a]*Residual fuel: 2,7% sulfur content.*

[b]*Distillate fuel: 0,5% sulfur content.*

[c]*Slow speed engines.*

[d]*Medium and high speed engines.*

[e]*Slow speed engines.*

[f]*Medium and high speed engines.*

The final emissions will vary depending on the fuel consumption. It is hard to generalize the fuel consumption of ships due to the multiple factors that influence final fuel consumption. In table 5 we can observe how fuel consumption changes depending on the speed and size of the vessel.

Table 5: Fuel consumption measured in tons per day for selected speeds and vessel size (Notteboom and Cariou, 2009).

	Fuel consumption (tons/day)									Ship size (TEU)
	105	125	150	175	200	230	270	310	370	10000+
	80	100	120	140	160	190	220	250	290	9000-10000
	75	90	110	130	150	170	200	230	260	8000-9000
	70	80	90	110	130	150	175	200	230	7000-8000
	50	60	70	80	90	110	130	150	170	5000-6000
	45	55	65	75	85	100	120	140	155	4000-5000
Speed (knots)	17	18	19	20	21	22	23	24	25	

4.3.2 Train

For the emission factors for railway, EcotransIT has a good overview. Their emission factors are presented in EcoTransIT's methodology (ifeu Heidelberg et al., 2018).

Emission factors for rail will depend on multiple factors such as weight, energy consumption, origin of energy and the geography of each country. EcotransIT uses figures obtained directly from the railway companies with supplementation from the International Union of Railways and scientific literature. Regarding the origins of energy, the numbers used are obtained from Eurostat for European countries and the International Energy Agency for the rest (ifeu Heidelberg et al., 2018). As a result, they present a large dataset of emission factors which take many considerations into account. The emissions factors that are relevant for our railway routes are presented in table 6.

Table 6: Emission factors for rail Well-To-Tank (WTT) in g/MJ for electric locomotives and PEF per country (ifeu Heidelberg et al., 2018).

Emission factors (WTT) g/MJ					
Country	CO2	NOx	SO2	PM	PEF
China	332	0,873	0,758	0,125	3,55
Kazakhstan	242	0,492	0,314	0,066	3,99
Russia	229	0,414	0,257	0,05	4,02
Belarus	242	0,492	0,314	0,066	3,99
Poland	324	0,629	0,883	0,116	3,03
Germany	189	0,245	0,23	0,028	2,46
EU28	137	0,319	0,345	0,041	2,62

In table 7 and 8 we have the emission factors for rail pertaining to wear and tear and diesel locomotives. The figures presented in table 7 pertaining to wear and tear is the same for all trains, both diesel and electric.

Table 7: Emission factors for rail from wear and tear (TTW) in g/tkm (Otten et al., 2017).

Emission factors (TTW) g/tkm			
CO2	NOx	SO2	PM
0	0	0	0,006

Table 8: Emission factors for rail (diesel) (TTW) in g/tkm (Otten et al., 2017).

Emission factors diesel (TTW) g/tkm			
CO2	NOx	SO2	PM
18	0,24	0,0001	0,007

The emission factors presented in table 6 have been developed by EcotransIT. EcotransIT is a calculation tool that was developed in the early 2000’s as a response to an increased demand from companies to know the environmental impact from their transport activities. The creation of the tool was a result of cooperation between the Institute for Energy and Environmental Research (IFEU) from Heidelberg, the Öko-institut from Berlin and the Rail Management Consultants GmbH (RMCon/IVEmbH) from Hanover.

In addition to these institutions, the project was also initiated by the five European railway companies DB Schenker Rail, Schweizeriche Bundesbahnen (SBB), Green Cargo AB, Trenitalia S.p.A and Société Nationale des Chemins de Fer Français (SNCF). In later years, the railway companies Red Nacional de los Ferrocarriles Españoles (RENFE) and Société Nationale des Chemins de fer Belges (SNCB) has also joined the project.
All of these partners are providing the tool and database with information on a regular basis according to new information and national policies (EcoTransIT World, 2019a).

What makes EcotransIT a great tool is that it sources information on a continuous basis from reputable companies and institutions, and that it takes into account multiple factors when calculating emissions. Among them, factors such as electricity mix and topology (EcoTransIT World, 2019a). The scientific basis for the tool comes from three recognized institutions: IFEU is the first institution and they are behind the development of the "TREMOD- Transportation Emission Model". A model that is being used as the basis of emissions and climate protection reporting in Germany. The second institution is INFRAS which have developed the "Handbook on Emission Factors for Road Transport (HBEFA). This document serves as the core emission data base in Europe. Lastly, IVE mbH Hannover is behind the methodology of the routing and distance calculations. The transport networks used are being continually updated (EcotransIT World, 2019b).

Energy consumption

Using EcotransIT's calculation tool, we calculated the energy consumption and distance for each country for both railway corridors (EcotransIT, 2019). As the emission factors are denoted in grams per Mega Joule (MJ), energy consumption will be presented in MJ. The energy consumption shown in table 9 and 10 is the energy used for transporting one FEU over the presented distances in both railway corridors.

Table 9: Energy consumption and distance (New Eurasian Land Bridge)

Energy consumption and distance (New Eurasian Land Bridge)					
Country	Distance (KM)	Energy (MJ)	PEF	Diesel (KM)	Electricity (KM)
China	4260	34903	3,55		4260
Kazakhstan	2768	3555* 25445	3,99	498	2270
Russia	2728	28871	4,02		2728
Belarus	617	6435	3,99		617
Poland	668	5326	3,03		668
Germany	379	2452	2,46		379
Total	11420	106987		498	10922

**Diesel*

Table 10: Energy consumption and distance (Trans Siberian)

Energy consumption and distance (Trans Siberian)					
Country	Distance (KM)	Energy (MJ)	PEF	Diesel (KM)	Electric (KM)
China	1497	6479 4450*	3,55	804	693
Mongolia	1090	7777*	N.A	1090	
Russia	6131	62237	4,02		6131
Belarus	617	6435	3,99		617
Poland	668	5326	3,03		668
Germany	379	2452	2,46		379
Total	10382	95156		1894	8488

**Diesel*

In this paper, the energy consumption in MJ is only relevant when looking at electric locomotives. This is due to diesel emission factors being denoted in g/tkm. As such, the energy consumption in MJ for diesel trains are visualized for comparison purposes only.

Primary energy factor

In the context of emission factors for trains, there is another factor that is important to include. As railways are to a large degree powered by electricity, it is important to know the PEF. The PEF can simply be calculated by dividing the raw primary energy demand of electricity generation by the electricity produced (Esser and Sensfuss, 2016). In simple terms, the factor denotes the amount of energy input needed to produce one unit of energy. The PEF can also be modified to include factors such as transmission and distribution losses or energy used to extract, clean and transport the fuels needed to produce energy (Esser and Sensfuss, 2016). As for railways, the PEF can be useful when looking at locomotives that are being powered by electricity. The reason being that by dividing the total emissions with the PEF, we remove the emissions that are not exclusively connected with the propulsion of the train. This allows for a fair comparison as the extraction and production of fossil fuels are not considered for the other modes in the comparison.

4.3.3 Truck

For the trucking emissions factors, we have chosen to use numbers from a CE Delft report written by Otten et al. (2017). The factors can be seen in table 11.

Table 11: Emission factors for trucks tank-to-wheel (TTW) in g/tkm for a heavy weight container transport.

Paper	CO_2	SO_2	NOx	PM
Otten et al. (2017)	61	0,0004	0,3	0,008

The factors presented are based on average figures and do not differentiate between motorway and urban driving. These figures are denoted in TTW which means that only emissions from propulsion of the vehicle is taken into account.

4.4 Calculations

To be able to assess the environmental impacts of the different modes along the different routes, we need to convert our emission factors into numbers that present the total emissions for each corridor. As this is a comparative assessment with focus on the environmental impact of container trade, these calculations will be used in the form of an analysis that looks at a baseline scenario and comparing this to alternative scenarios. Here we put different variables that might change the outcome of each mode's performance such as electricity-mix, new regulations and service speed of the oceangoing vessels. From the calculations we make, and the alternatives, we will be able to address the severity of pollutants both in urban and rural areas and discuss which corridor has the most severe environmental, ecological and health impacts.

4.4.1 Railway routes

The calculations for the railway routes will be conducted with the emission factors presented earlier by ifeu Heidelberg et al. (2018) and Otten et al. (2017). Considering that major parts of both corridors are electrified, the source of the electricity is of great interest as different countries produce electricity from different sources. This can ultimately have an impact on the calculations as the emission factors are denoted in WTW. In practice, this means that emissions from electricity generation is taken into account (ifeu Heidelberg et al., 2018).

The formula used to calculate emissions for trains are found below. In the equation E_{MJ} denotes energy in MJ, EF_e denotes emission factors for electric locomotives, EF_p denotes the PEF, EF_d denotes emission factors for diesel locomotives, W_l denotes the loaded weight of the train and D_{km} denotes distance travelled in kilometers.

$$E = \frac{\left(\frac{E_{MJ} * EF_e}{1000}\right)}{EF_p} + \frac{\left(\frac{EF_d * W_l * D_{km}}{1000}\right)}{FEU}$$

This equation can be used to calculate the airborne emissions for the compounds CO_2, NO_x and SO_2. In the case of PM, the equation needs to add another calculation that includes the emissions of PM from wear and tear. This factor remains the same for both diesel and electric locomotives as these emissions are unrelated to the engine used to power the locomotive. The equation used to calculate the total PM footprint is presented below.

$$E = \frac{\left(\frac{E_{MJ} * EF_e}{1000}\right)}{EF_p} + \frac{\left(\frac{EF_d * W_l * D_{km}}{1000}\right)}{FEU} + \frac{\left(\frac{EF_{TTW} * W_l * D_{km}}{1000}\right)}{FEU}$$

In this equation, EF_{TTW} denotes the emission factors for TTW referring to PM emissions. By using this equation, we can calculate the emissions specific to each different country. The finished calculations for each corridor are found in table 12 and 13 below.

Table 12: Types of emissions and their impact for each country given in kg.

New Eurasian Land Bridge	CO2	NOx	SO2	PM
China	3264,17	8,58	7,45	1,23
Kazakhstan	1767,38	6,13	2,00	0,51
Russia	1644,64	2,97	1,85	0,36
Belarus	390,29	0,79	0,51	0,11
Poland	569,51	1,11	1,55	0,20
Germany	188,39	0,24	0,23	0,03
Total	7824,38	19,83	13,59	3,99

Table 13: Types of emissions and their impact for each country given in kg.

Trans-Siberian	CO_2	NOx	SO_2	PM
China	967,72	13,41	1,39	0,37
Mongolia	490,50	6,54	0,00	0,19
Russia	3545,34	2,97	3,98	0,77
Belarus	390,29	0,79	0,51	0,11
Poland	569,51	1,11	1,55	0,20
Germany	188,39	0,24	0,23	0,03
Total	6151,76	25,06	7,65	3,23

We are assuming that the length of the train is 750m, with a maximum weight of 1000t as presented by ifeu Heidelberg et al. (2018), the capacity of TEU's is in the range of 80-100. For our calculations the amount of TEU's are 80 which translates to 40 FEU's.

There are some stretches done by truck on all three routes. One stretch is on the sea route from Zhengzhou to Qingdao. The other is the final leg from Hamburg to Oslo, which is performed by truck on both rail routes. On this leg, the truck will avoid the ferry from Denmark to Norway by using the Öresund bridge connection. This means that the whole route will be calculated using the same factors. We follow the Euro VI standard for diesel engines with the corresponding emission factors provided by Otten et al. (2017). Thus, the calculations are as follows.

$$E = \frac{(W_l * E_f * D_{km})}{1000}$$

In the formula, W_l denotes the gross loaded weight of the vehicle. In this case 40 tons. E_f denotes the emission factors. Lastly, D_{km} denotes the distance travelled in kilometers. The equation is then divided by 1000 to get the result in kilograms. The following calculations are valid for the Hamburg to Oslo leg. Zhengzhou to Qingdao leg will be similar but with D_{km} being 744km.

$$CO_2 = \frac{(40 * 61 * 1065)}{1000}$$

$$CO_2 = 2599$$

$$SO_2 = \frac{(40 * 0{,}0004 * 1065)}{1000}$$

$$SO_2 = 0{,}02$$

$$NO_X = \frac{(40 * 0{,}3 * 1065)}{1000}$$

$$NO_X = 13$$

$$PM = \frac{(40 * 0{,}008 * 1065)}{1000}$$

$$PM = 0{,}34$$

The final and total emissions for the two railway alternatives are presented in table 14 and 15.

Table 14: Total emissions Siberian railway corridor in kg per FEU.

Emissions per FEU for the Siberian route	CO_2	SO_2	NOx	PM
Zhengzhou - Hamburg (Rail)	6152	7,65	25	3,23
Hamburg - Oslo (truck)	2599	0,02	13	0,34
Total	8751	7,67	38	3,57

Table 15: Total emissions Eurasian railway corridor in kg per FEU.

Emissions per FEU for the Eurasian route	CO_2	SO_2	NOx	PM
Zhengzhou - Hamburg (Rail)	7824	14	20	3,99
Hamburg - Oslo (truck)	2599	0,020	13	0,34
Total	10423	14,02	33	4,33

4.4.2 Sea route

The first part of the sea route starts with a trucking leg from Zhengzhou to the port of Qingdao. As the calculation method has already been described in the previous section, it will not be elaborated on further. The finished calculations are found in table 16.

Table 16: Truck emissions from Zhengzhou to Qingdao in kg per FEU.

Emissions for truck in kg	CO_2	SO_2	NOx	PM
Zhengzhou - Qingdao	1815	0,01	9	0,24

Calculating emissions for ships can be quite the task considering how many variables we must take into consideration. Fuel consumption for ships are heavily affected by size, load factor, operating speed, voyage duration, regulatory areas to mention some. As our voyage stretches from China to Europe, we have made some assumptions based on literature and studies that we believe represent the type of container transport envisioned for our thesis. From this we have come up with a series of parameters for our calculations. The ship is the COSCO Shipping Aries with a nominal capacity of 19273 TEU's. We assume a capacity utilization of 90% based on an estimate from the Asia to US West Coast trade, which we believe can be translated to the Asia – North West Europe trade (Stopford, 2009, CMA CGM). The load factor of 90% refers to the number of slots that are being used as a percentage of the total available. To stay within the weight limit of the ship, we must assume that not all containers on the ship are as heavy as the one used in our example. As we can observe in figure 12, speed plays a major role for fuel consumption as it has an exponential nature. This means that higher speed leads to exponentially higher fuel consumption. Ships will therefore try to maintain the most efficient speed but at the same time keep transit times reasonable. (CMA CGM) has given an operating speed for vessels at 19000 TEU's at 22 knots which is a little lower than the design speed of 23 knots.

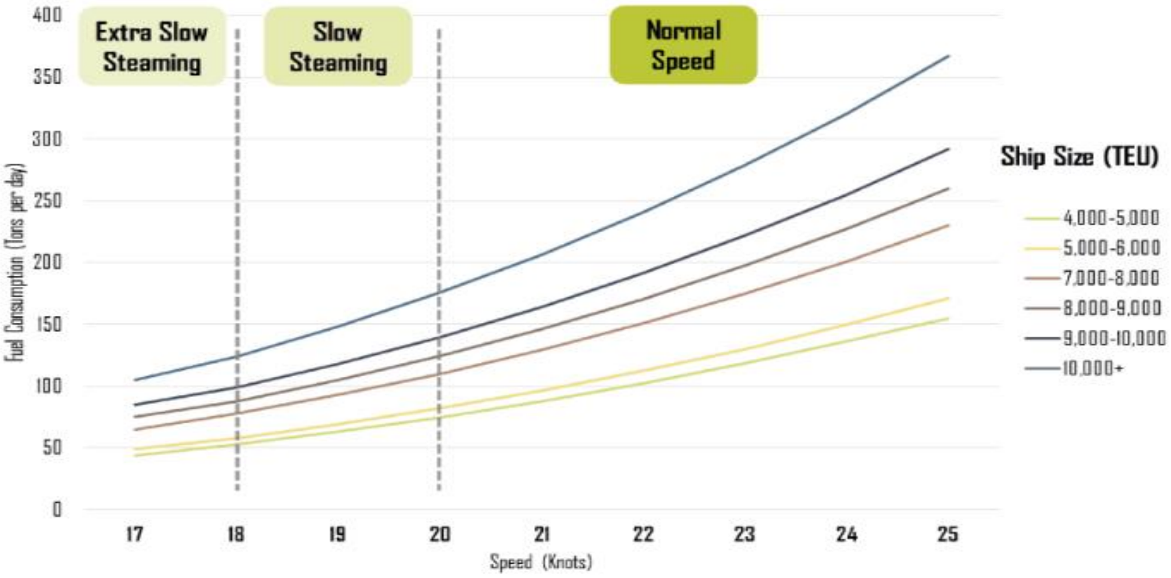


Figure 12: Fuel consumption by vessel size and speed. Source:(Notteboom and Cariou, 2009) Adopted by: (Rodrigue, 2017)

However, this is between terminals. We also must consider navigation within ports and time spent at berth which adds on to the emissions that can directly affect human health. The operating speed might prove to be higher than what is realistic today. Bunker fuel constitutes quite a significant cost in liner shipping operations (Stopford, 2009). As we can observe in figure 12, one of the most effective ways of reducing fuel consumption, and therefore costs, is to sail at a slower speed. Sailing at a slower speed is often referred to as "slow-steaming". "Slow-steaming" is a practice that shippers utilize during periods of low demand, high fuel prices, low freight rates and overcapacity (Finnsgård et al., 2018). With the introduction of larger vessels for shippers to capture an even greater market share, the container shipping market suffers from overcapacity. This makes it difficult for shippers to make above normal profits (Hirata, 2017). As a result, liner operators must implement measures to reduce costs, with "slow-steaming" being one option.

To start off the calculations we need to have a set of emissions factors, which are an average of those stated in table 4. In addition, emission factors for SO_2 from burning Marine Diesel Oil (MDO) with lower sulfur content, i.e 0,1%, is obtained from Svindland (2018). The emissions factors that will be used are therefore those stated below in table 17.

Table 17: Emission factors in kg/t fuel burnt from ships.

Fuel	CO2	SO2	NOx	PM
HFO	3097	50	86	6,8
MDO 0,1	3097	2	86	6,8
MDO 0,5	3097	10	86	6,8

To measure fuel consumption, we need to consider multiple factors. First, the time spent at sea and in ports. Information from the French Asia Line 2 gives us a transit time from Qingdao to Hamburg of 36 days (CMA CGM). Using figures from Stopford (2009), we assume that the vessel spends on average 2,4 days per port call. This means that out of the 36 days in transit, 12 days are spent in port assuming 5 port calls between Qingdao and Hamburg. Second, we need to know the amount of fuel burned per day. According to Chrzanowski (1985), ships in port have a fuel consumption of 15% of the amount at sea. So, for 12 days of the journey in port, the fuel consumption per day will be significantly lower than the rest of the remaining 24 days at sea. We assume a speed of 18 knots, giving a daily fuel consumption of roughly 125 tons at sea, and 19 tons in port. The total fuel consumption will therefore be as follows:

$$T = (D_s * F_s) + (D_p * F_p)$$

$$T = (24 * 125) + (12 * 19)$$

$$T = 3228$$

In the equation, D_s denotes the amount of days at sea and F_s denotes the fuel consumption at sea. Subsequently, D_p denotes the amount of days in port and F_p denotes the fuel consumption in port. The total fuel consumption is therefore 3228 tons for the entire journey from Qingdao to Hamburg. With this number in mind, we can use the emission factors in table 17 to calculate the total emissions. This is done by multiplying the emission factors (E_f) by the amount of fuel burnt (F_b). In this equation, we assume the use of MDO with 0,1% sulfur content to be used in port to power the auxiliary engines. To get a better overview, the final emissions are converted into tons instead of kilograms at the final stage of the equation. The total emissions from the route Qingdao to Hamburg is therefore calculated as follows:

$$E = \frac{(F_b * E_f)}{1000}$$

$$CO_2 = \frac{(3228 * 3097)}{1000}$$

$$CO_2 = 9997$$

$$SO_2 = \frac{(3000 * 50) + (228 * 2)}{1000}$$

$$SO_2 = 150{,}46$$

$$NO_X = \frac{(3228 * 86)}{1000}$$

$$NO_X = 278$$

$$PM = \frac{(3228 * 6{,}8)}{1000}$$

$$PM = 22$$

The COSCO Shipping Aries has a nominal capacity of 19273 TEU's. Assuming a load factor of 90%, we can expect the Aries to load 17375 TEU's on its voyage to Europe. In FEU's this translates to roughly 8673. Further, by dividing the total emissions by the number of loaded containers, we get the emissions per FEU.

The same formulas were used on the leg Hamburg to Oslo which is serviced with the ship Bianca Rambow (CMA CGM). However, the parameters are significantly different as the ship is much smaller than the COSCO Shipping Aries. Using figures from Stopford (2009), we arrived at a fuel consumption of 36,3 tons per day. Furthermore, the voyage takes 2 days which gives us a final fuel consumption of 72,6 tons. On the short sea leg from Hamburg to Oslo, SO_2 emissions are heavily reduced as the North Sea is a SECA. In this area, only fuel with a sulfur content of up to 0,1% is allowed since 2015 (Ledoux et al., 2018). Because of this regulation, lower sulfur fuel is used, reducing the SO_2 footprint. The final emissions from the two sea legs are found in table 18.

Table 18: Total emissions and emissions per FEU on short and deep-sea legs. In tons.

Emissions	CO2	SO2	NOx	PM
Ship total deep sea	9997	150,46	278	22,0
Per FEU	1,15	0,02	0,03	0,003
Ship total short sea	225	0,15	6,24	0,494
Per FEU	0,576	0,000	0,016	0,001

After summing up all the different legs on the sea route, we arrive at the final emission numbers which can be observed in table 19. In this table, the numbers are converted back into kilograms.

Table 19: Total emissions for the sea route in kilograms per FEU.

Route	CO_2	SO_2	NOx	PM
Zhengzhou - Qingdao (Truck)	1815	0,01	9	0,24
Qingdao - Hamburg (Deep sea)	1153	17,3	32,0	2,5
Hamburg - Oslo (Short sea)	576	0,4	16,0	1,3
Total	3543	17,7	57,0	4,0

The total emissions per FEU for all three corridors is presented in table 20. Our findings indicate that sea transport has significantly lower emissions of CO_2 compared to the railway alternatives. On the other hand, sea transport has higher emissions of SO_2 and NO_x. Emissions pertaining to PM are similar to the railway routes.

Table 20: Total emissions for the different corridors in kg per FEU.

Route	CO2	SO2	NOx	PM
Sea Route	3543	17,7	57	4
Rail (Siberian)	8751	7,67	38	3,57
Rail (Eurasian)	10423	14	33	4,33

4.5 Route characteristics

In previous chapters we have looked at the different routes and how emissions are calculated for each route and mode of transport. Based on this information, we know how large the emissions are and which countries and regions the different routes pass through. In this chapter, we will go further into detail about what characterizes the different routes. This information is important when looking at how emissions to air affect the areas surrounding the routes.

Several conditions come into play along the relevant routes at hand. What does the population density look like for the countries that the railway routes pass through? How do the different countries produce the electricity that the trains run on? How close to residential areas do the maritime fairway pass? Conditions like these affects how the route is rated environmentally and will be assessed in this chapter. Here we will look at the characteristics for each route to map the possible areas that will be affected by the emissions pertaining to the route. Especially population density and power generation will be covered for the railway route, while urban areas close to the maritime fairway will be of interest for the sea route.

4.5.1 Railway corridors

One of the main factors that differentiate the railway corridors from shipping and road is the fact that major parts of both corridors are electrified. If the trains travel along these routes they will not need diesel-powered locomotives that are the main contributors to local air pollutants such as PM, NO_x and SO_2. Even though electricity-powered locomotives have low emissions compared to their diesel counterparts, different countries produce electricity in different ways. For example, some countries such as Kazakhstan, produce most of their electricity from coal. This can cause a spike in emissions of SO_2 as we can observe in table 20 where the Eurasian corridor has almost twice the emissions of SO_2 compared to the route through Siberia.

The two rail corridors go through the same amount of countries. However, the Russian leg is longer for the Siberian route with 6000km compared to the Eurasian route with ~2600km. On the other hand, we have China and Kazakhstan dominating the Eurasian route along with Russia with 3700km and 2200km respectively. These differences can be detrimental when it comes to both production of electricity, which we have already touched upon, and how close to urban areas the two routes are in total along the way to Hamburg.

Electricity mix

As the train goes through the different countries along the route towards Hamburg, there will be different “electricity mixes” in each country. This is because countries have different methods to produce electricity. Emissions from the production of electricity can be emitted far away from the actual railway line. As a result, emissions can be more damaging for local areas close to the power plants, while regionally they might not be as severe. In table 21, the electricity mix in different countries along the railway route can be observed.

Table 21: Electricity mix for different countries along the railway routes.

Country	Coal	Other
China (IEEFA, 2019)	59%	22% Nuclear power and renewable energy 3,8% Wind 15,2% Other
Mongolia (JCM, 2016)	90%	6% Import 3% Wind 1% Hydro
Kazakhstan (IEA, 2016b)	79,8%	7,6% Wind 4,8% Biofuels 4,7% Gas 1,6% Hydro 1,4% Oil
Russia (Gorbacheva and Sovacool, 2015)	18%	18% Hydro 17% Nuclear 46% Gas
Poland (IEA, 2016c)	79,8%	7,6% Wind 4,7% Gas 4,8% Biofuel 1,6% Hydro 1,4% Oil
Belarus (IEA, 2016a)	0,1%	96,9% Natural gas 1,3% Nuclear and Thermal 1,7% Oil
Germany (Energiebilanzen, 2018)	35,3%	12,8% Natural gas 35,2% Renewables 11,7% Nuclear 4,3% Other

Population densities

Population densities in different countries, as well as previous research on emissions to air for the relevant areas will be important to look at to assess how emissions affect the different parts of the routes. The population densities can help us define the most crucial areas that get affected by air pollutants as well as how close population dense areas are to the railway-tracks. By doing this we can combine the population density map with the map of the different rail routes.

As both railway routes are roughly the same length and have relatively similar emissions, the main factor when comparing these routes in an environmental perspective will be how the urban areas are affected. For example, the Eurasian route goes through China to the west while the Siberian route travels north through Beijing and towards Mongolia.

China is a population dense country, especially to the east as illustrated by Tan et al. (2018) in their mapping of the population density from 2000 to 2010.

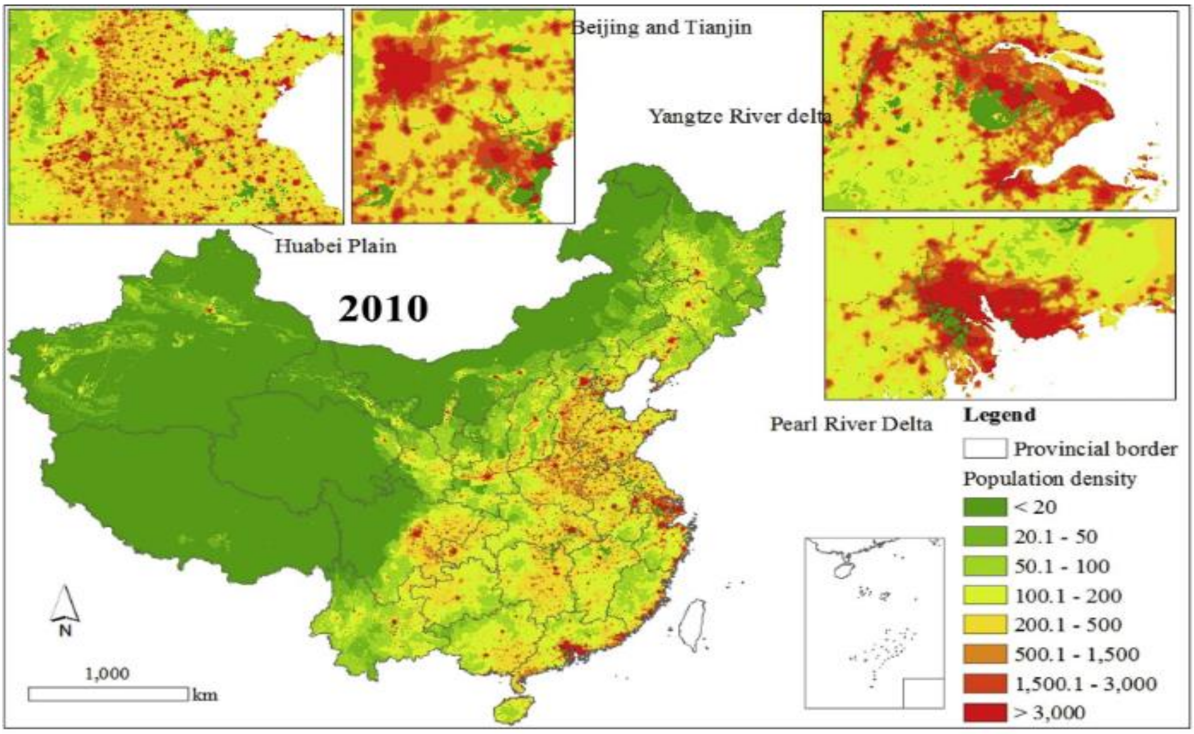


Figure 13: Population density in China 2010. Source: (Tan et al., 2018)

As we can observe, the population density going west is drastically lower compared to the eastern part of the country. Still, the corridor through the Eurasian land bridge is located close to the northern border which is more population dense than other parts of western China as we can see in figure 13. This means that a larger part of urban areas is affected by the Eurasian route compared to the Trans-Siberian one through China.

As for the Trans-Siberian route towards Yekaterinburg, the population density is low compared to other European countries. Parts of Siberia often has a population density below one person per square kilometer (Yegorov, 2016). Compared to the other countries that are involved in these routes, Russia has the lowest population density by far, probably only matched by Kazakhstan as shown in figure 14:

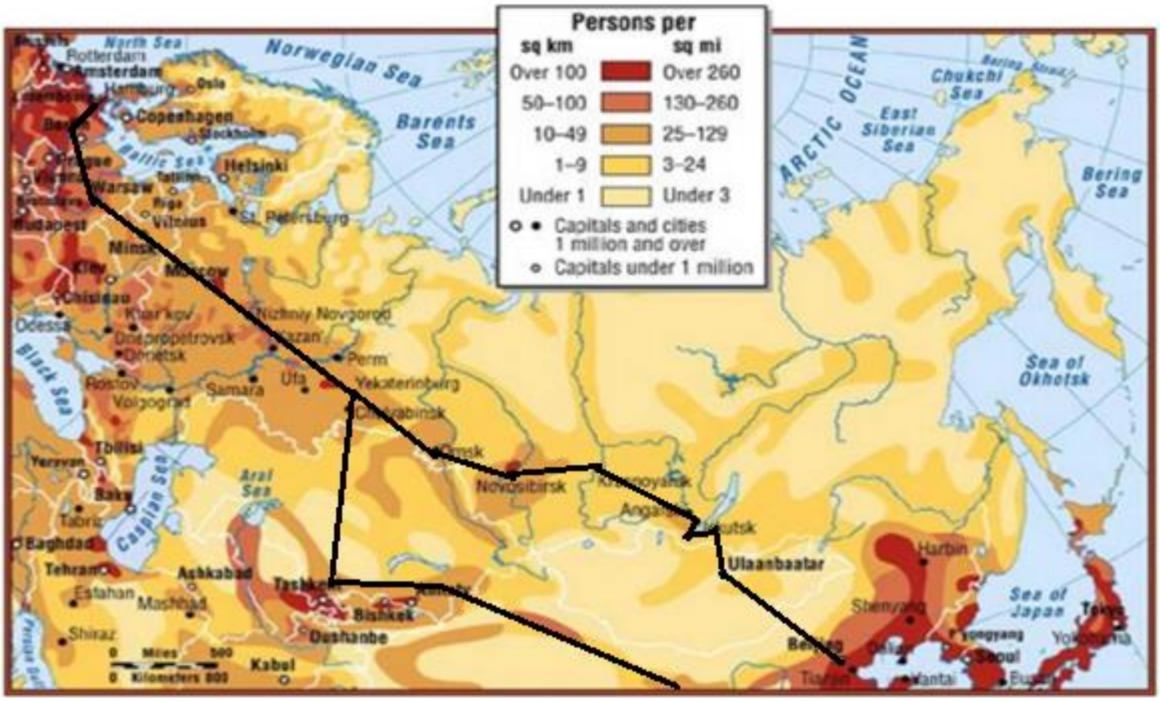


Figure 14: Population density in Russia/Siberia. Source: (Yegorov, 2016)

There is a considerable increase in population density from Yekaterinburg where both the routes go through. Before this point, we see that the Siberian route has areas that are sparser populated compared to the Eurasian corridor that follows the darker areas at the bottom of figure 14 towards Almaty.

Russia’s population density sits at 8.4 people per square kilometer which makes this one of the most sparsely populated countries in the world (Karachurina and Mkrtchyan, 2015). As 6000km of the Trans-Siberian route goes through Russia with its spread-out population, it can prove to be the deciding factor when discussing which route has the most severe environmental impacts.

Stretches towards Yekaterinburg

One of the reasons why the trans-Siberian corridor is of interest, despite its current lack of infrastructure, is the desolation along the route. While the Eurasian land bridge uses the enhanced infrastructure through China and Kazakhstan before arriving in Yekaterinburg, the Siberian route has already been using Russia’s deserted areas from Ulan-Ude towards Yekaterinburg. Both stretches are, as mentioned earlier, electrified. Our assumptions are that where electrified railways are available, they will be used. Thus, we will have to go deeper into the production of electricity in Russia and Kazakhstan.

The main difference between these two routes is the first half of the route before both railways meet up in Yekaterinburg. Our calculations show that there is quite a difference in emissions of SO_2 as well as PM. The Siberian route has the lower emissions for both. As both routes are the same from Yekaterinburg, these differences must have occurred before this point when both lines were separate.

Electricity generation by conventional fossil fuel plants, especially from developing countries, has caused severe environmental problems both for GHG emissions as well as other air pollutants such as SO_2. On the topic of developing countries power generation such as China and Kazakhstan, several scientific papers point to the fact that: "*For developing countries like China, who often rely on coal-fired power generation due to its resource endowment and competitive cost of coal, the issue of environment pollution caused by coal-fired power plants is even more significant"*(Du and Mao, 2015, Zhang et al., 2015). Considering that approximately 80% of Kazakhstan's energy generation comes from coal power plants (Kadrzhanova, 2013), it is probable that the high SO_2 emissions on the Eurasian route arises from the electricity production from coal. On the other hand, we have Russia, where even though the country has a large portion of global coal production, most of their electricity comes from natural gas (Gorbacheva and Sovacool, 2015). Gorbacheva and Sovacool (2015) mention on the topic of emissions to air and environment, that Russia does not have "*electrostatic precipitators, which reduce particulate matter"* for a majority of their power plants and "*venturi scrubbers"* on less than half. We assume that Kazakhstan does not meet these standards either, and therefore has higher amounts of SO_2 and PMs compared to their Russian counterpart due to their higher reliance on coal.

Yekaterinburg to Europe.

Both corridors meet up in Yekaterinburg and stays the same from that point until Hamburg. For this part of the route the comparison between railways will be unnecessary as we assume the same load factor and weight for both trains. We will still analyze how the route from Yekaterinburg to Hamburg affects the surrounding areas in accordance with population density and generation of electricity compared to other parts of the route, as well as compared to the maritime alternative that we will touch upon later.

By looking at the population density map given in figure 14, we can see that there is an increase in population density the closer we get to Hamburg from Yekaterinburg with an average density between 10-100 people per square kilometer. Onwards from there it only gets denser as the trains approach Hamburg. As for the population density on this stretch, we will look at Europe as a whole because of the similarities between the countries.

Figure 15: Population density in Europe. Source: (EY, 2017)

Figure 15 shows the high population density in central Europe. Our route does not touch the most highly populated areas. Rather, it goes through Moscow, Minsk and Warsaw towards Hamburg, thus only grazing the most populated areas in Europe. If we compare this part of the corridor to the previous ones, we see that the population density across Europe is higher than several parts of the route through Russia and Kazakhstan. Most of the route through Europe has a population density above 10 people per square kilometer with some areas as high as 100 people per square kilometer. With the population density being this high, especially in Poland and Germany, emissions for these areas can be of relevance as the production of electricity for railways will affect a significant amount of people wherever the power plants are located. This is particularly the case where the use of fossil fuels for electricity generation is widespread.

Power generation in Belarus, Poland and Germany

From the earlier parts of the route we have seen that electricity produced from coal has been a crucial factor for emissions of SO_2 and PM. To what extent coal is used for production of electricity in the different countries, if any at all, will therefore be of interest.

Belarus

From Moscow both routes enter Belarus towards Minsk, which we can see has the lowest population density of the three countries along the route. When it comes to production of electricity Belarus is the 13^{th} largest importer of natural gas for energy with over 95% of electricity generated from natural gas (IEA, 2016a).

Poland

Close to the border between Poland and Belarus we find the city of Małaszewicze where a change into European track gauge is required to travel further. From here on the railway goes through Warsaw towards Hamburg. Poland gets most of their electricity produced from coal. In fact, 89% of their electricity came from hard coal and lignite, while only 6% came from renewable sources in 2010 (Paska and Surma, 2014).

Germany

The final stretch done by railway is through Germany, which is the country with the highest population density along the route. Germany is close to having more than 100 people per square kilometer across the country, except for a few areas having between 50-100. The energy situation in the country is a mix between coal, lignite, nuclear, gas and renewables. "*Until 2010, half of all domestically produced energy came from coal and lignite; the rest came from nuclear, gas and renewables* (Renn and Marshall, 2016). While Germany has been phasing out the nuclear energy power production while increasing the focus on renewable energy, coal and lignite production has remained almost static over the last decade but has dropped down to a share of 35,3% (Appunn, 2019).

Even though Germany is planning on getting rid of power from coal completely by 2038, they still have many power plants running on coal. Lignite is the main power source constituting 22.5% of gross power generation. The figure for hard coal is 12.8%.

Because of lignite's presence within power generation in Germany, German lignite plants make up seven out of Europe's 10 biggest polluters. 55,3% of emissions in Germany came from coal fired power plants in 2016 (Appunn, 2019, Sandbag, 2017)

Hamburg to Oslo

Delivering door-to-door has become an important asset that has to be met by all transport service providers, which leads to trucks being an important transportation method. Road transport is also known to be one of the leading emitters of air pollutants having 72% of CO_2 emissions pertaining to transport and 17% of total global emissions (Uherek et al., 2010). We expect the stretch by road, even though it has relatively high emissions, to have a low local impact because of where the route is located. The stretch from Hamburg to Oslo moves northbound to less and less populated areas which means that fewer people will be affected by emissions from trucking.

4.5.2 Sea corridor

The first part of the trip between Zhengzhou and Qingdao is located close to the parts of China with the highest population density which can cause higher negative effects than other parts of the country. As China has been a country with high economic growth, the growth in traffic related pollution has been detrimental for the environmental problems in the country, especially close to urban areas. The route moves from west to east which means that it will stay close to highly populated areas the whole way.

As the ship in the corridors are only propelled by their own engines, factors such as energy production of the respective countries are to a large degree irrelevant when looking at the sea route. However, emissions originated from ship engines will have implications for the route as described in earlier chapters.

The ship calls at several ports along its route, with many being in Asia and Europe. Container ships have been proven to contribute to a relatively large amount of pollution despite their port calls being shorter on average (Merk, 2014). However, emissions of SO_x and PM are lower at EU ports than in other ports which is to a large degree a result of stricter regulations in these ports than elsewhere. The port with the highest emissions is Singapore which is part of the route from Qingdao to Hamburg (Merk, 2014).

Qingdao to Singapore

The route from Qingdao to Singapore is categorized by a routing that is close to the coastline of major urban populations such as Hong Kong, Taipei and Shanghai. As a result, the impact of ship pollutants will have a larger negative human health effect than if the routing was further away from the coast. The shipping lane between the two points is heavily trafficked which further amplifies this issue. This part of the route is also outside ECAs which means that NO_x and SO_2 emissions are relatively high. Until the new IMO regulations come into force in 2020, this remains a significant issue. Further along the route the ship enters the South China Sea which is an open stretch of sea quite far away from land. On this stretch, local pollution is not a very large problem. However, pollutants from SO_2 and NO_x still has the possibility to damage ecosystems at sea. The ship calls at 2 ports on the route from Qingdao to Singapore, those are Shanghai and Ningbo. While the ship is in port it will contribute to the emissions to air of the nearby areas.

Singapore to Suez Canal

From Singapore the vessel navigates through the Strait of Malacca, a heavily trafficked shipping lane of major economic importance. Over 70 000 vessels transit through the strait every year, and it is estimated that one-third of all traded goods in the world and almost half of the world's oil shipments pass through the strait, with an estimated value of over 1 trillion U.S. Dollars (Gilmartin, 2008, Gangopadhyay, 2013). The Strait of Malacca has large problems with pollution. However, a large amount of these problems come as a result of wildfires that occur from clearing land to be used for agriculture (Velasco and Rastan, 2015). The haze that occurs from these fires lowers the visibility for ships, something that can make ships with outdated navigation equipment prone to accidents (Gangopadhyay, 2013). While the Strait of Malacca has received plenty of attention due to its importance as a shipping lane, the airborne pollutants from shipping in the region has gained relatively little attention as the water quality has posed a greater concern. Oil spills and operational discharges from shipping seems to be of major concern in the region (Abdullah et al., 1999). Further on, the ship leaves the Malacca Strait and continues its journey on the Indian Ocean. This part of the voyage is takes place on the open ocean, except for a small stretch outside of Sri Lanka. Airborne pollutants will therefore have limited effect on the local areas. This continues all the way to the Red Sea and the entrance to the Suez Canal.

Suez Canal to Hamburg

The final stretch of the deep-sea voyage goes from the Suez Canal to Hamburg. Traffic at the Suez Canal is substantial and there are good reasons to believe that this will affect the local environment. As the ship passes the Suez Canal and enters the Mediterranean ocean, the ship will continue its journey close to coastal areas. The next port of call is Piraeus in Greece. Research on the topic of emissions to air in this port does exist, however it mostly focused on the passenger port. A plausible reason for this is that the passenger port is located closer to the city than the container port. While not directly comparable, there are some aspects of the research that can prove to be relevant to the container port as well. Shipping activities have negative effects on human health and the built environment surrounding the port. Emissions of NO_x, SO_2 and $PM_{2,5}$ in particular contributes to negative externalities (Tzannatos, 2010). We have good reason to believe that these pollutants are also a source of concern in the container port as it is also located close to the urban area. Another side effect of maritime emissions, especially NO_x, is the increase in ozone (Poupkou et al., 2008). This further leads to the creation of photochemical smog which is a big problem in the Mediterranean Sea, especially in the summer due to increased sun radiation (Goldsworthy, 2002, Poupkou et al., 2008).

After calling at the port of Piraeus, the vessel continues its voyage through the Mediterranean Sea where it crosses the Strait of Gibraltar into the Atlantic Ocean. The vessel continues through the open sea at the Bay of Biscay before entering the English Channel which is a SECA. As opposed to the Mediterranean Sea where emissions of SO_2 and NO_x leads to an increase in surface ozone, emissions of these pollutants cause a decrease in surface ozone when released in and around the English Channel (Aksoyoglu et al., 2016). The final port call before reaching Hamburg is Rotterdam. Rotterdam is one of the busiest ports in the world and one can therefore expect it to be especially exposed to airborne pollutants from ships. However, stricter EU regulations leads to lower relative emissions of SO_2 and PM than elsewhere (Merk, 2014). In the Port of Rotterdam, industry is in general a larger emitter of airborne pollutants than ships. This is particularly the case for SO_2 and NO_x, but not for PM (Den Boer and Verbraak, 2010). After calling in Rotterdam, the vessel enters the Port of Hamburg which is where the container gets unloaded.

Hamburg to Oslo

The final leg of the sea route takes place between Hamburg and Oslo. On this leg the container is moved to a feeder container vessel for the final hop. This part of the voyage is located exclusively in a SECA which means that SO_2 emissions will be lower. The reduction in allowed sulfur content in fuels have resulted in significantly lower SO_2 emissions compared to before the policy was enacted (Svindland, 2018). Most of the time on this voyage is spent out in open sea. This means that the effects of emissions to air on human health is significantly reduced. The vessel will reach Oslo after a couple of days and the containers are unloaded at its destination.

4.6 Uncertainties and alternative assumptions

The calculations previously presented are our baseline scenarios. These calculations show how the scenarios most likely are with today's standard practices. However, there are several uncertainties that might alter the results from the calculations both for shipping and railway. We will present three alternative calculations with corresponding emissions. These are: (1) the new sulfur regulations that will come into effect in 2020 that allow a maximum sulfur content of 0,5% for fuel on ships, (2) the operating speed of vessels that affect the fuel consumption and (3) "what-if" the whole railway stretch had an EU-mix in the production of electricity.

4.6.1 Operating speed of vessels

Even though liner operators have to a large degree settled on a lower sailing speed, it must be noted that the vessels being used are designed to operate at a higher speed. In the case of increased freight rates and demand, the speed of vessels is assumed to increase to add more freight capacity in the market (Finnsgård et al., 2018). As such, we have decided to include a scenario with a higher operating speed of 22 knots. As we can observe in table 22, an increase in speed to 22 knots leads to an increase in airborne emissions by a significant amount. By increasing the speed of the vessel from 18 to 22 knots, the journey between Qingdao and Hamburg takes 33 days instead of 36. Thus, increasing the freight capacity on the route. An interesting observation is that despite the increase in speed, the sea alternative still comes across as favorable regarding CO_2. However, in the case of SO_2 and NO_x there is an increased spread compared with rail. For PM the new scenario makes sea transport unfavorable compared to rail.

Table 22: Airborne emissions in the different corridors. High speed scenario

Route	CO2	SO2	NOx	PM
Sea Route 22 Knots	4261	28,32	76,92	5,61
Rail (Siberian)	8751	7,67	38	3,57
Rail (Eurasian)	10423	14	33	4,33

4.6.2 EU electricity mix for the whole railway route

As we have seen through the previous calculations in this chapter, emissions for railway are influenced by the countries the route passes through due to countries having different sources of electricity. The alternative scenario of having the routes solely powered on an EU28 electricity mix is more of a "what-if" scenario compared to the two other alternative scenarios. Nevertheless, it is of interest to see how the emissions change under this scenario.

Table 23: Emissions from rail with EU electricity mix in kg (Eurasian corridor).

New Eurasian Land Bridge (EU mix)			
CO_2	NOx	SO_2	PM
8231,57	15,60	26,62	3,76

By applying the EU electricity mix for the whole route, we see a reduction in emissions across all four emission types for the Eurasian route as observed in table 23. The most considerable pertains to the reduction of CO_2 that goes down more than 2100kg as electricity produced from coal is reduced. For the other emissions we also see reductions because of a likely improvement from the production in Kazakhstan and China if they were to have an EU electricity mix.

Table 24: Emissions from rail with EU electricity mix in kg (Trans-Siberian corridor).

Trans-Siberian (EU Mix)			
CO_2	NOx	SO_2	PM
7787,66	21,48	23,92	3,53

For the Trans-Siberian corridor, the changes are not as prominent compared to the Eurasian corridor as we can observe in table 24. Nevertheless, there is a reduction in CO_2 of about 1000kg. For SO_2, we observe an increase in emissions. In the case of NO_x and PM, there is a slight decrease compared to the baseline scenario.

4.6.3 IMO 2020

As previously mentioned, the IMO is set to implement new regulations in 2020 pertaining to the maximum amount of sulfur permitted in marine fuels. The new regulations will require marine fuels to have a maximum sulfur content of 0,5% outside of SECAs, down from 3,5% currently. This will require ship owners to consider new abatement options such as low sulfur fuels, exhaust gas cleaning systems i.e "scrubbers" or alternative fuels (IMO, 2019). The results of an IMO 2020 scenario are shown in table 25.

Table 25: Airborne emissions in the different corridors. IMO 2020 scenario.

Route	CO2	SO2	NOx	PM
Sea Route IMO2020	3543	3,89	57	4
Rail (Siberian)	8751	7,67	38	3,57
Rail (Eurasian)	10423	14	33	4,33

As we can observe, the emission of SO_2 is significantly reduced in the IMO 2020 scenario. The reduction in SO_2 is so large that the sea route comes across as more favorable than both railway alternatives. As the PM emissions are roughly equal for sea compared to rail, it is safe to conclude that with the new IMO regulations the sea alternative comes across as very attractive in an environmental perspective.

4.7 Summary of findings

The total emissions per FEU for all three corridors is presented in table 26. Our findings indicate that sea transport has significantly lower emissions of CO_2 compared to the railway alternatives. On the other hand, sea transport has higher emissions of SO_2, NO_x and equal emissions of PM.

Table 26: Total emissions for the different corridors in kg per FEU.

Route	CO2	SO2	NOx	PM
Sea Route	3543	17,7	57	4
Rail (Siberian)	8751	7,67	38	3,57
Rail (Eurasian)	10423	33	20	4,33

All three routes that have been analyzed passes through areas with major urban populations. The effects on the environment does however differ quite significantly. Sea transport comes out as favorable compared to rail in a climate perspective due to its low emissions of CO_2. In addition, the sea alternative has higher emissions of SO_2 and NO_x which contributes to global cooling.

Shipping is therefore a net contributor to global cooling in the short term. In the long term however, shipping contributes to a slight increase in global warming.

Rail comes across as favorable regarding the effects on ecosystems and human health due to its lower emissions of SO_2, NO_x and PM, even with the alternative scenarios we see that rail has the edge here. However, while sea transport has higher emissions of these pollutants, the areas that are affected may be equal or less than for rail. This comes down to the area in which the emissions to air takes place. Ships emit much of their emissions at open sea as opposed to the power plants at land that produces the electricity that powers the locomotives.

5.0 Discussion

Throughout this thesis we have elaborated on the emissions caused by transportation and energy production. In addition, we have analyzed different routes suitable for container transport from China to Europe. The research questions at hand have also been touched upon but has not been thoroughly discussed yet. Especially question two and three will be further discussed in this chapter as they are the most critical for the thesis. Up until now we have focused on looking at the different corridors separately and how they perform in an environmental setting as well as calculating how alternative scenarios might alter the results. For this chapter we will set them up against each other and see how they compare and discuss how alternative factors might affect the results.

It is important to pinpoint that our calculations are based on certain assumptions pertaining to weight, load factors, type of route, type of vehicles/vessels, electricity mix and operating speeds. The numbers will vary depending on these factors. However, for our thesis we have set up some alternative calculations that gives us a deeper understanding of how the operations can get affected by different variables.

5.1 Total emissions

None of the routes has only one mode of transport. Total emissions for each route will therefore be determined by how the route is set up, and what mode of transportation is involved. An example from one of our corridors is the maritime corridor which includes two feeder links. The container has to be transported from Zhengzhou to Qingdao by truck. Once trucks come into the equation, we see a drastic change especially in CO_2. The leg done by road from Zhengzhou to Qingdao has a total of 1815 kilograms CO_2 emitted per FEU on a stretch of 750km compared to a total of 1153 kg per FEU for 20440km by sea. This proves that the mode of transport has a significant impact on the total emissions of each corridor. The same can be observed on the railway routes, where the final trucking leg from Hamburg to Oslo increases the total CO_2 footprint of the corridors significantly. In the case of railway, another important detail to keep in mind is the fact that most of the emissions is calculated from WTW. This means that the emissions are heavily influenced by the electricity mix in each respective country.

For the noxious gases covered in this thesis we see that the deep-sea route has considerable higher emissions compared to railway. Even with the superior economies of scale, we see that the sea route has more than double the emissions of NO_x and higher SO_2 compared to both of the routes done by rail per FEU. The only scenario where shipping has a lower emission to air in any of the categories other than CO_2 is with the IMO 2020 scenario where SO_2 emissions decrease from 17,7kg per FEU to 3,90kg.

For CO_2 there is a clear advantage going to sea-going vessels as these have significantly lower emissions compared to rail. This is also on a route that is nearly double the distance which makes it clear that for a non-area specific emission, the sea route has a clear advantage per FEU compared with the railway routes. Overall the railway alternatives seem to come across as less favorable than the sea alternative. This can to some degree be attributed to comparative lack of economies of scale. Railways going to Europe are severely limited by the lack of length and height compared with railways on other continents such as North America (Furtado, 2013).

5.2 Impacts on climate

The impact from the different alternatives on climate will depend on which pollutants are dominant for each mode. In general, emissions of CO_2 are the dominant factor affecting global warming. On the other hand, emissions of NO_x and SO_2 contribute to global cooling (Fuglestvedt et al., 2008). As a matter of fact, shipping is a net contributor to global cooling in the short term, although that is expected to change in the coming years due to new IMO regulations on sulfur content in fuel oil (IMO, 2019, Lindstad et al., 2015, Fuglestvedt et al., 2008). The effects of the new IMO regulations can be seen in figure 16. As we can observe from the figure, both NO_x and SO_2 contributes significantly to the cooling of the planet in a 20-year perspective.

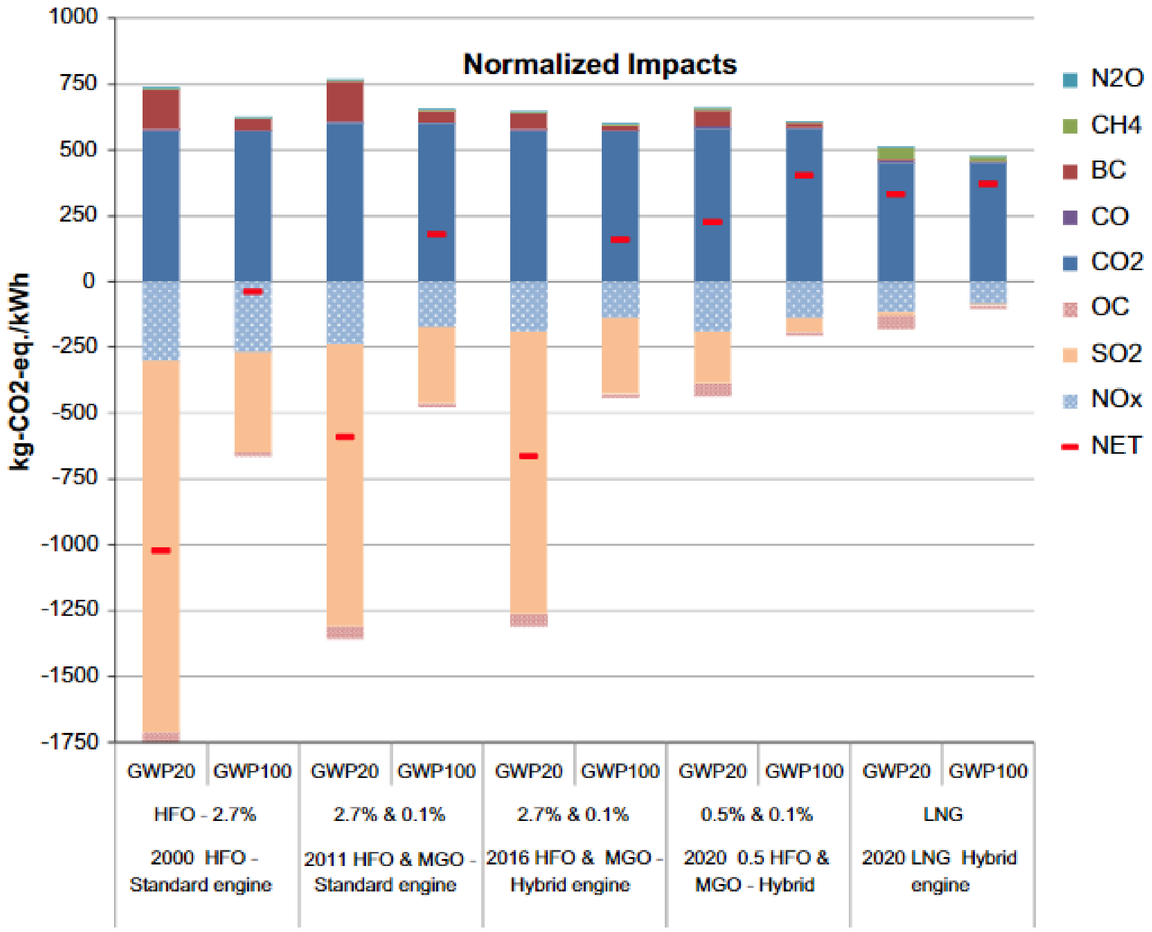


Figure 16: Average global warming impact over 20- and 100-year horizon in kg CO_2-equivalents per 1000 kWh for the investigated trades (25% of distance in ECA) as a function of fuel, legislation year and power setup (standard or hybrid). Figured obtained from Lindstad et al. (2015).

This means that the negative climate forcing from the shipping industry ends up cancelling out the positive climate forcing from the entire aviation sector in the short term (Fuglestvedt et al., 2008). In the long term, shipping still contributes to global warming to a small extent. However, when new sulfur emission regulations come into force in 2020, the shipping sector will become an even greater net contributor to global warming.

Railways are generally seen as an environmentally friendly mode of transport. Our research shows that this claim is not true in the case of the China-Europe trade. This is primarily due to two factors. The first is the use of diesel locomotives on tracks which are not electrified. Second, the source of electricity in the countries where tracks are electrified. In countries such as Kazakhstan and Russia large parts of the electricity generation comes from fossil fuels such as natural gas and coal (Kadrzhanova, 2013, Gorbacheva and Sovacool, 2015).

The result is that CO_2 emissions are higher than for ship per FEU if the source of electricity is considered. Thus, the effects on global warming is higher for rail than for sea transport over this distance.

5.3 Local impacts

An important aspect when looking at emissions is the comparative environmental footprint of the modes. Certain pollutants such as CO_2 affects climate globally, and do not differentiate between the areas it gets released. However, pollutants such as NO_x, SO_2 and PM has local effects which means that the area of release is of importance. The sea route is by far the largest emitter of these pollutants. In practice, this implicates that shipping will have a larger local footprint compared to rail. However, much of the emissions takes place at open sea where the effects on human health are negligible. While humans remain relatively unaffected by emissions at sea, ocean ecosystems may suffer. It also has to be noted that even though the majority of emissions of NO_x and SO_2 is released at open sea, the pollutants can still be transported inland and affect local populations. Parts of the route enters densely populated maritime fairways such as the Malacca strait, the Suez Canal and the strait of Gibraltar, as well as ports. The largest negative effects appear when the ship is at berth. Most of the ports that the ship calls at during the voyage to Europe is situated close to major urban areas. As such, emission of noxious gases has an impact on ecosystems and the overall health of the local population as described in chapter 3.3.2 and 3.3.3 respectively. Especially acidification, acid rain and smog are area specific pollution that have severe effect on human health and ecosystems. While noxious gases have a significant negative impact on local areas, it can be argued that in a global perspective they might be beneficial. Due to the release of noxious gases, shipping comes across as very favorable in a climate change perspective due to the cooling effect of SO_2 and NO_x.

In the case of the railway alternative, it is harder to pinpoint exactly where the emissions take place as the rail lines are to large degree electrified. As such, the source of power, i.e. power plants, are not known. However, it is generally assumed that these power plants are in vicinity of sub-urban populations. This assumption is made because power plants require skilled personnel and infrastructure for its construction and operation. As a result, industrialized areas are preferable to rural areas (Barda et al., 1990). The emissions of harmful pollutants are lower than for the ship alternative by a significant margin. This does not necessarily mean that railways have lower local impact.

Generally, it is safe to assume that while railways have a lower local footprint if we look exclusively at the amount of pollutants it emits, the emissions from power plants are for the most part taking place on land. This is not the case for ships where a lot of the emissions takes place at open sea. However, the difference in emissions from these pollutants are so significant that it is possible to conclude that railways are marginally better than shipping when it comes to the effects on local areas.

5.4 Future developments and alternative assumptions

The transportation sector is constantly having to adapt to changes with new technologies emerging, new regulations calling for change in operations, global warming that can lead to the opening of new routes, etc. Technology and regulations work as improvements that the transportation companies will have to adapt to stay competitive, while the opening of a new route for liner shipping could be a game changer for shipping between the Far East and Europe.

5.4.1 Northern Sea Route

The Northern Sea Route (NSR) has become an intriguing topic with the continuous melting of the polar ice. Reducing lead times can be invaluable for the sustainability of modern shipping and has been an important topic alongside greener solutions for transportation. With the possibility of halving the transit time from 37 days through the Suez-Canal down to 19 days through the NSR, it can have a large impact on shipping between the Far East and Northern Europe both on reduction of emissions and transit-times (Buixadé Farré et al., 2014).

There are, however, pretty severe obstacles that have kept the liner business away from the NSR. As it currently stands, the operating costs are high because of the ice-breaker tariffs, liability/insurance costs and the cost of having to build ice-class ships. The capital costs and operating costs for these ice-class vessels only operating during the five-month window in the arctic does not currently outweigh the year-round usage of the Suez-Canal (Zhang et al., 2016). Transit times are also one of the main arguments for why the NSR can be viable in the future. As it currently stands, the ice along the route hinders effective sailing through the passage.

Liner shipping needs to follow strict schedules and can therefore not gamble on the ice being in a favorable condition every time a transit is scheduled. If the ice were to melt, and become easier to predict, transit times would become possible to improve, but this will be several decades away. There are also other limitations hindering this route such as infrastructure, the political situation between Russia and the west and economic viability. However, they do not add to the environmental aspect.

The current ice-conditions along the route means that “blue water vessels” cannot travel through without the help of ice-breakers. Also, considering the difference between sailing in ice-infested waters versus blue-water sailing because of more resistance, greater engine-power and heavier weight of the ice-class vessel, an ice-class vessel can have an added fuel premium of 30% compared to blue-water vessels (Zhang et al., 2016). For the environment this means that there are possibilities reducing emissions because of the shorter distances, even though they currently are quite minimal because of the vessels and conditions in the arctic. As for the location, in the future to be able to move more shipping north to these desolated areas can have positive impacts when it comes to area specific emissions to air. To move these away from the highly populated fairways along the route through the Suez-Canal and up to the desolated NSR can be a positive future possibility. However, for the ice to melt enough for good conditions year-round in the arctic, it could take several decades for this to become viable.

5.4.2 IMO 2020

Through our baseline and alternative calculations, we have seen several factors that alter the environmental impacts of the different routes. New regulations from the IMO pertaining to the maximum allowed sulfur content in marine fuels will alter the results of this study by a significant amount. The new regulations will require shipping companies to use fuels with a maximum sulfur content of 0,5%, down from 3,5% today. Shipping has a drawback compared to railways when it comes to noxious gases. However, with the new regulations the shipping industry will make solid progress to close this gap. It is important to keep in mind that the new regulations only regulate sulfur content. This means that other noxious gases such as NO_x and PM will still be a larger problem for the maritime sector compared to railways. Another factor that needs to be taken into consideration is that when the new regulations come into force, the climate advantage shipping has compared to rail will be reduced due to a reduction of the cooling effect provided by SO_2 and NO_x.

In any case, the shipping alternative will still be the more favorable option in an environmental perspective after the IMO 2020 regulations come into force.

5.4.3 A switch to renewable energy

From a railway-perspective, the origins of energy to fuel the electrified trains becomes important. As we have seen in previous chapters there are quite a few different approaches to production of energy between the countries involved in the routes. Some have the majority of their electricity generated from coal, while others have started the shift over to sustainable renewable energy. Globally speaking we see a shift over to renewable energy with an estimated 19,1% of global final energy consumption sourced from renewables in 2013, looking to increase to 39% by 2050 as optimistically estimated by the International Energy Agency (Bhattacharya et al., 2016).

The EU has their own goal called "*The Energy 2020 – A strategy for competitive sustainable and secure energy"* (Scarlat et al., 2015). This shows an incentive for countries to move over to renewable energy with the focus on sustainability. On the other hand, we have the countries outside the EU such as Belarus, Russia, Kazakhstan, Mongolia and China. However, we assume that the countries outside the EU also has an incentive to move over to sustainable, renewable energy. How this will affect future emissions from production of energy can give railway a competitive edge in green logistics in the long term.

To visualize a switch to renewable energy we looked at an alternative calculation for railway with an EU electricity mix. In the calculation we have included all countries, even those outside the EU, as this will be an important factor as we have seen from the emission factors given by EcotransIT. For most countries an EU electricity mix will be favorable, however for Russia's SO_2 emissions it will have a negative effect. For the Siberian route with a Russian stretch of more than 6000 kilometers this will have a negative effect on the emissions, even though it is favorable for the other instances.

6.0 Conclusion

In this thesis we have made an environmental comparison between one sea route and two railway routes from Zhengzhou, China to Oslo, Norway. The background for our thesis is the growing focus on greener transport solutions and the emergence of railway as an alternative to Shipping from China to Europe. Emissions from railways are calculated using WTT and TTW that we combined to get WTW, which takes the energy mix of each respective country into account. Our research focused on the four airborne pollutants CO_2, NO_x, SO_2 and PM.

Our findings indicate that maritime transport has significantly lower emissions of CO_2 on this route compared to the railway alternatives. On the other hand, emissions of SO_2 and NO_x are significantly higher for maritime transport compared to railways, while PM emissions are comparable. CO_2 is well known to cause global warming, and it is therefore possible to conclude that the sea route comes across as less damaging in a climate perspective than the railway route. In addition to CO_2, the higher emissions of SO_2 and NO_x from ships cause a net global cooling effect in the short term.

Railways have a significantly lower footprint of noxious gases and particles such as NO_x, SO_2 and PM. These gases and particles can prove detrimental for human health and ecosystems with direct exposure. Negative health effects also arise from indirect ambient exposure to these gases and particles over a longer time period. In the case of the sea route, negative health and ecological effects from emissions of noxious gases and particles are to some degree mitigated by ship emissions taking place at open sea. Despite this, the differences in emissions of noxious gases and particles between sea and railways are so great that railways come across as more favorable when it comes to local impacts.

6.1 Limitations

A case with a wide scope will naturally be subject to uncertainties. It is therefore important to pinpoint these uncertainties and establish their relevance. Our dataset has been built with the contribution of many different sources. As such, there might be contributions that can alter the results. The emission factors used in our analysis are all based on a wide consensus across multiple papers.

However, this does not mean there are no flaws with the calculations or numbers being used. As with all modes of transport, emissions will depend on many different factors. Such factors may include load factors, weather, equipment, routing and others.

Regarding emissions and their effects, there are also certain uncertainties. While some papers are very clear on the negative health effects from long-term exposure of certain pollutants, other papers struggle to find any relation. Much of the literature on health effects measure direct exposure and is for that reason not relevant when trying to pinpoint the effects of ambient emissions to air. While it does seem to be some correlation between the effects of emissions on human health and ecosystems, there is still uncertainties on whether the scenarios depicted in these studies can be directly translated to our thesis.

6.2 Suggestions for further research

For further research on this topic, we would suggest moving to the next step on the IPA. Because of the limited scope of this thesis we were not able to monetize the impacts of emissions. By having this step examined it would give a more real perception of the impacts that emissions can have on society. External costs would help determine which types of emissions to air that has the most severe impact on a more thorough level than comparing which mode has the most of each pollutant during their route.

Relating to the IPA and a more thorough study, it would be interesting to see how the different corridors compare if WTW for all modes of transport were to be included. This includes the emissions from the production of electricity in the case of rail, and the emissions from petroleum extraction and refining for fossil driven vehicles and ships.

We also see the possibilities of comparing the modes at a later point after the IMO 2020 regulations has come into force. We conducted this thesis one year before the IMO 2020 regulation and could therefore only speculate how this regulation would change the emissions connected to shipping. By revisiting this thesis at a later time and compare this with another comparison made after the regulations have come into effect could be interesting to see how the regulations have affected the competitiveness between the modes.

Further research could focus on a future scenario in which an energy mix containing more renewable energy is used. It would be interesting to see how this would change the environmental competitiveness of the railway alternatives.

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