Master's degree thesis

LOG950 Logistics

Combined slaughtering and transportation - An evaluation of the "Hav Line method" as a transport alternative for fresh farmed salmon from Norway to Europe

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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 begun in December 2017 and finished in May 2018. During this time, it has been both an inspiring and an educational journey to write this thesis. Including to this, it has been interesting to analyze a possible future solution for transportation in detail, especially for an industry like the Norwegian salmon farming sector. Our work has in some periods been time consuming and for some parts challenging. However, we can say that we are satisfied with our final result and think that everything was worth the effort.

We want to especially thank our supervisor Harald Hjelle, who helped us through the entire creation process of this thesis. This support started with the first conversations about a possible topic and continued through the complete writing process. The conversations we have had with our supervisor have supported us and gave us ideas and guidance for improvements during our work.

During the years at Molde University College, we have also had many lecturers that have provided us with a foundation for the writing of this thesis. We also want to thank them for always having time for discussions, conversations and help.

We would also like to express our gratitude to our classmates, friends and family that have been going through this period with us. You have all been motivating and supportive for us. It would have been a much less fun experience without you.

Summary

At present, Norway is one of the largest exporters of seafood worldwide. Especially salmon can be regarded as one of the most important export commodities for the country, only behind petroleum products. Estimations for the future show that salmon exports will increase by a fivefold by 2050. This means that the importance of the seafood- and salmon farming sector will further grow over the next decades. For Norway as a country, this growth will contribute to economic stability and create jobs. It will however also lead to an increased demand for transport to export markets. Transport to foreign markets is today mostly conducted via road transport and there are a number of negative aspects that are associated with this mode of transportation. The challenges that arise with this growing transport demand will increase in line with the predicted growth of the whole salmon farming sector.

One way to deal with the high demand for transport operations, is a possible shift of road freight activities to sea. When analyzing the characteristics of sea transport and the possibilities along the Norwegian coastline, sea transport seems like a viable option for the purpose of fresh farmed salmon export. However, alternative solutions with sea transport have to make sense on a variety of perspectives. Solutions will be only useful to the problem and implemented by the industry, if they are reasonable in an environmental and economical context.

One of the possible alternatives is the so-called Hav Line method. This innovative solution will involve a new vessel type that is going to combine the slaughtering and transport processes of farmed salmon. The Hav Line method is the central topic of this thesis. The vessel will start its operation along the Norwegian West Coast in the third quarter of 2018 and transport fresh farmed salmon directly from its point of production to processing facilities in Hirtshals (Denmark).

One research issue of this thesis is to explain the differences between this new way of exporting salmon and business-as-usual transport operations for the same purpose. The central topic is to evaluate the Hav Line method regarding its environmental performance, specifically emissions and socio-economic costs. The results of this evaluation are compared with results from two selected business-as-usual transport alternatives, in order to see which solution is more suitable for the task. The last observed area pertains a

possible application of the Hav Line method on a larger scale, i.e. further up in the North of the Norwegian coastline.

The applied research methodology for the mentioned aspects is a mixed method, containing qualitative as well as quantitative elements and is used for a case study of the Hav Line method. Information provided by Hav Line Gruppen AS and related research papers on the subject of seafood transport, sea transport in general and the Norwegian salmon farming industry, are our main sources of data.

The main objective of this thesis is to evaluate if this specific sea transport alternative can be applied as a solution for the arising challenges of the salmon farming industry regarding increasing transport demand. The thesis only focuses on the export of fresh farmed salmon to the European market.

List of abbreviations

AE	Auxiliary engine
AEP	Auxiliary engine power
AWL	Average engine workload
CA	Loading capacity
CO_2	Carbon dioxide
EEA	European Economic Area
EP	Engine power
FAO	Food and Agriculture Organization of the United Nations
FC	Fuel consumption
FHF	The Fisheries and Aquaculture Industry Research Fund
GHG	Greenhouse gas
HGV	Heavy goods vehicle
IPCC	Intergovernmental Panel on Climate Change
KNH	Kristiansund & Nordmøre Port
Knot	Nautical mile (1.852 km)
LF	Load factor
LNG	Liquefied natural gas
ME	Main engine
MEP	Main engine power
MGO	Marine gasoil
NOx	Nitrogen oxides
NM	Nautical miles
NTP	National Transport Plan
PM	Particle matter
Ro-Ro	Roll-on-Roll-off
Ro-Pax	Ro-Pax factor
SECA	Sulphur Emission Control Area
SFC	Specific fuel consumption
SINTEF	Stiftelsen for industriell og teknisk forskning
SO_X	Sulphur oxide
SSS	Short sea shipping
TØI	Norwegian Institute of Transport Economics

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1.0 Introduction

This first chapter of this thesis is separated into four parts, which should give the reader an overview of the thesis. An introduction to the topic of fresh farmed salmon transportation and related issues inclusive relevance of the thesis is given in subchapter 1.1 – research relevance. The further subchapters contain an explanation of the selected research questions and of the thesis structure.

1.1 Research relevance

Seafood in general, has been an important commodity for the Norwegian economy for a long time. This is shown by the fact that the industry is in second place when it comes to the value of goods exported from Norway, ranked only behind the petroleum sector. The year 2017 for instance, represented another record-high in seafood exports, worth an astonishing 94.5 billion NOK. Approximately two thirds of this value, or about 65 billion NOK in numbers, were generated by exporting salmon, the most important species for the Norwegian seafood respectively aquaculture industry (Norwegian Seafood Council 2018b).

Even though Norwegian seafood is exported to all continents, the EU remains the largest market by importing seafood from Norway with a total value of 61 billion NOK in 2017 for all fish species (Norwegian Seafood Council 2018b). Salmon exports to the EU accounted thereby for 45.7 billion NOK, a number that underlines the importance of salmon as a valuable export commodity for the Norwegian economy (Norway´s Seafood Council 2018a). However, when it comes to export, there is of course a strong need for transportation to the respective markets. In the case of export to the EU or the European mainland in general, the most common mode of transportation is road transport, which fulfils many of the criteria that are necessary for the transportation of fresh salmon, but there are also some problems associated with this mode.

The transportation of fresh salmon requires certain standards and the applied transport method has to meet a variety of criteria in order to be a suitable choice. Since fresh fish is a highly perishable good, it is crucial that the transport processes are carried out in a fast and efficient manner. This means on one hand that the used transport chains have to be designed as so-called “cold chains” in order to provide the probably most essential foundation for the transport of such a perishable good. On the other hand, there is also pressure on the lead time of a delivery. The pressure occurs because the whole operation should be realized in the shortest possible time. Lead time and temperature during transport can have a tremendous impact on the quality of salmon meat and so on the market value of it. Fresh fish loses a significant proportion of its original value when transported without any special precautions to maintain the freshness or when the time required for transportation is simple too long. The loss of value is estimated to be 20-25% after two days and close to 100% after four. This loss of value pertains situations where fresh salmon is not transported appropriately on the way from farms to retailers (Larsen 2003).

Additionally, to the basic requirements of the permitted temperature during transport and lead time, it is also important to keep other selection criteria for transport modes in mind. In this case, such aspects would be self-evidently the transportation costs, flexibility of the available transport network, predictability of the transport mode and further factors that might influence the quality of the salmon meat when in transit. Due to these mentioned selection criteria, the currently most applied modes of transport for the export of fresh salmon from Norway are air and road transport, whereby the lastly mentioned mode is usually used for the European market as aforementioned (Eidhammer et al. 2002). However, road transport is also associated with many negative aspects and cannot be regarded as the most sustainable long-term solution for the transportation of fresh salmon from Norway to Europe.

Road transport can be made accountable for a large degree of environmental pollution caused by traffic and further external effects that lead to socio-economic costs for the affected parts of the society. Typical examples here for would be road wearing, traffic congestions or accidents. Due to these negative characteristics associated with road transport, it is currently one of the main objectives of policy makers in the EEA and Norway to reduce the amount of transports carried out by trucks and other road vehicles. Including to the goal to reduce transport by truck, another objective is to reallocate value streams to other transport modes, preferably to sea and rail. This incentive is also recorded in the Norwegian National Transport Plan (NTP 2013), which was issued by the

Norwegian government. Generally, the incentives in the NTP, aim for more efficiency and sustainability within the transport sector in Norway in order to sustain or even increase the competitiveness of the country’s businesses and industry, promote regional development and improve urban environments (NTP 2013).

The NTP includes many targets in different areas related to transport, traffic and mobility. One important objective of this plan is to achieve a shift of commodity flows from road to sea and rail transport. Therefore, it is necessary that the Norwegian government is going to strengthen the competitiveness and attractiveness of transport by these modes. One of the characteristics of the Norwegian transport sector in general are higher logistics and transportation costs due to high labor costs, dispersed settlement and long distances, both within the country and to export markets, compared to countries Norway’s industry is competing with. Due to this, Norway has to create a modern and efficient transport network, which is able to compensate these competitive disadvantages (NTP 2013).

The fishing industry, respectively the aquaculture industry, is one of Norway’s most important sectors as mentioned at the beginning. Because of this, it would be crucial for the abidance of the set goals in the NTP, to implement the proposed changes in this particular sector and achieve a stronger shift from the currently preferred road transport to sea transport or eventually other alternatives. According to Larsen (2003), Norwegian salmon exporters state that logistical processes including transports to Europe are at times inefficiently organized. Further, the winter months are a potential threat to the Norwegian fishing industry due to rough weather conditions, which can lead to difficulties for the maintenance of stable deliveries when using trucks for the export. This pertains especially to seafood producers in Northern Norway and can lead to a loss of market share (Larsen 2003). This a further reason to achieve a shift to other transport modes.

However, the perhaps biggest issue for the salmon producing industry and related transport activities is the predicted growth of the sector in the next 30+ years. This growth is of course highly desirable for Norway as a whole and single municipalities involved in the farming and processing operations. Nonetheless, it is not desirable regarding the eventual increase of road transport, since there are already sections in the Norwegian road system that are strained under the current traffic volume, especially for heavy goods vehicles (HGV). Given a five-fold predicted volume growth for farmed salmon in 2050, road transport looks even less like a suitable transport method for salmon exports in the future (Dekkerhus 2017).

Currently, some projects ongoing are trying to enable a shift from road to sea or eventually rail transport. The central issue of this thesis is to evaluate the so-called "Hav Line method" and compare it against a business-as-usual transport operations, regarding environmental-friendliness and related external effects. The Hav Line method encompasses a new vessel type, which combines the slaughtering process of salmon and further transport to processing facilities in continental Europe, so that road transport from Norway is completely redundant.

1.2 Research questions

The structure of the thesis follows the chosen research questions, which are separated into three different sections.

1. *How does the Hav Line method operate compared to a business-as-usual process in a comparable part of a conventional value chain in the salmon farming industry?*

This question is answered by explaining the Hav Line method inclusive structure and all process steps. Further, it is compared with the activities in a business-as-usual value chain in the salmon farming industry, staring from the slaughtering process. The research question is answered in Chapter 6.0 and includes the necessary background information about the project, as well as illustrations about the "old" and "new" value chains in order to show the differences.

2. *Evaluation of the Hav Line method regarding:*
   - *Is the sea transport alternative Hav Line method more environmental friendly than the business-as-usual transport solutions?*
   - *Can the Hav Line method reduce socio-economic costs caused by the transportation of fresh farmed salmon in Norway?*

The evaluation of the Hav Line method can be seen as the core topic of this thesis. The two mentioned research questions should answer the central question of, if this new method is a better solution than the business-as-usual transport for the export of fresh farmed salmon from Norway to Europe on an environmental consideration. The focus of the evaluation lies on the environmental aspects of salmon transport. It would have also been interesting to take a more detailed look onto financial aspects of the project, but this was unfortunately not possible due to missing data. The evaluation is done in Chapter 7.0, where calculations were used to obtain values for certain types of emissions and socio-economic costs.

3. *Is it possible to apply the Hav Line method on a larger scale and achieve a permanent shift from road to sea transport for the export of fresh farmed salmon?*

This is the last research question of this thesis and it should clarify, if it is possible to apply the Hav line method for more than just one specific route, respectively organization. The question is answered by looking onto the aforementioned evaluation and use the calculation models for possible other routes.

1.3 Structure of the thesis

The thesis consists of 12 chapters. Chapter 1.0 gives the reader an understanding of the topic, explains the relevance of the research problem, what type of research questions that will be focused on and how the structure of the thesis will be. In Chapter 2.0, the selected methodology for the thesis is described. Further on in Chapter 3.0, the relevant theory that the thesis is based on is presented.

The four basic transport modes are compared in Chapter 4.0 and a SWOT analysis for sea transport is conducted. The SWOT analysis is based on factors that many transporters, producers and distributors value as important when they choose what transport mode they want to use for their freight.

In Chapter 5.0, previously conducted studies concerning the same topics that this thesis does, are reviewed. Chapter 6.0 is where the Hav Line method is introduced, followed by an evaluation of the Hav Line method in Chapter 7.0. The evaluation focuses on the key factors and necessary assumptions for the different transport routes and calculations of the emissions and socio-economic costs for each of them.

Chapter 8.0 contains an extension of the evaluation for another possible location and route further up North in Norway. The example that was used is a route from Hitra to Hirtshals.

For Chapter 9.0, includes a sensitivity analysis regarding different transport volumes and their impact on emissions. Chapter 10.0 describes the limitations in this study. Chapter 11.0 suggests further research that can be done and Chapter 12.0 concludes the main findings and results in the thesis.

2.0 Methodology

This chapter should provide the reader with an overview of the applied methodology in this thesis. The purpose of this study is to evaluate a transport alternative for fresh farmed salmon from Norway to Europe and compare it against the currently applied business-as-usual transport solutions. Therefore, this paper focuses on a sea transport alternative, which will include a new vessel type that combines the slaughtering process of farmed fish with its transport to facilities for further processing. The evaluated transport operations are conducted between Norway and Denmark.

The evaluated case focuses on the so-called Hav Line method. It is one of the latest projects that has the goal to shift transport of fresh farmed salmon from road to sea. The new vessel will mainly go from Bergen to Hirtshals, and further might be deployed on other routes if its operation is successful. The evaluation of the Hav Line method includes a basic description of the method including a comparison of business-as-usual transport to Hirtshals by road transport and ferries. A further analysis of emissions and socio-economic costs caused by the transport alternatives was conducted in order to compare them. The thesis should also answer the question if this method could be applied on a larger scale. The thesis uses a mixed research approach and applies a case study approach. The qualitative research approach is used for the theory parts in the thesis, while the quantitative research approach is used for the evaluation and calculations.

2.1 Rationale for research method

When choosing a research approach, either a quantitative, qualitative or a mixed method can be chosen. For this thesis, a mixed method is selected and a case study approach is applied. “A mixed methods study can employ either the quantitative or the qualitative approach (or some combination)” (Creswell 2003, 76). Johnson and Onwuegbuzie (2004) have a more detailed definition of the mixed research method, they define it as “the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study”. Creswell (2003, p. 76) further states that the mixed method can be used to both “understand the relationship among variables in a situation and explore the topic in further depth”. This means that this thesis will both contain a qualitative research approach and a qualitative research approach. For the thesis, this is done by using qualitative data as a basis for a subsequent quantitative analysis.

The reason to why the mixed research method was chosen and not a “pure” qualitative or quantitative research was selected, is that the research questions could be only answered by applying elements from both methodologies. The qualitative research approach is used to summarize the theoretical background and previously conducted research. It was also used to obtain the necessary information about the Hav Line method and business-as-usual transport solutions. Further, the quantitative research approach compares the transport alternatives against each other, regarding emissions and socio-economic costs.

2.1.1 Qualitative research approach

For the research, a qualitative approach is used for the theory parts. “A qualitative approach is one in which the inquirer often makes knowledge claims based primarily on constructivist perspectives (i.e., the multiple meanings of individual experiences, meanings socially and historically constructed, with an intent of developing a theory or pattern) or advocacy/participatory perspectives (i.e., political, issue-oriented, collaborative, or change oriented) or both. It also uses strategies of inquiry such as narratives, phenomenology, ethnographies, grounded theory studies, or case studies. The researcher collects open-ended, emerging data with the primary intent of developing themes from the data” (Creswell 2007, p. 18). The qualitative approach uses methods such as field observations and/or open-ended interviews to gather data for the research. Field observations are done by examine the activities of the participants, with a goal to identify and find a pattern. With an open-ended interview, the goal is to collect a more detailed view from the ones participating (Creswell 2007).

The data sources used for the thesis when it comes to qualitative research is mostly collected through conversations, reports and presentations. These data sources Are mentioned in detail in Chapter 2.2.1.

2.1.2 Quantitative research approach

"A quantitative approach is one which the investigator primarily uses postpositivist claims for developing knowledge (i.e. cause and effect thinking, reduction to specific variables and hypotheses and questions, use of measurement and observation, and the test of theories), employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistical data" (Creswell 2003, p. 18). In other words, the quantitative research approach is based on data that can be measured. One of the most used methods for collecting data in the quantitative research approach are questionnaires. The questionnaires can either be fixed as multiple choice questions or as open, where the responder can answer what they want. A questionnaire that is open-ended gives the responders the possibility to answer whatever they want, without any limitations. These answers can be hard to analyze, but usually do not exclude any details since the responder can write longer answers. The multiple answer questionnaire is easier to analyze when it comes to comparing and analyzing trends, but it can limit the responder if their meaning is not one of the answers that can be chosen (Creswell 2003).

For the thesis, the data sources collected for the quantitative research, come mainly from articles and reports. These data sources are mentioned more in detail in Chapter 2.2.2.

2.1.3 Case study approach

Including to this, a case study approach for this research is used. "Case study research involves the study of an issue explored through one or more cases within a bounded system" (Creswell 2007, p. 73). Crowe et al. (2011) states that "the case study approach is particularly useful to employ when there is a need to obtain an in-depth appreciation of an issue, event or phenomenon of interest, in its natural real-life context". Creswell (2007) further mentions that the case study research can be done by collecting multiple sources of information (i.e. observations, interviews, audiovisual material, and documents and reports) from different sources. For the thesis, multiple different literature sources and interviews are used, in order to look at the Hav Line method and if it is obtainable to shift the transport of fresh farmed salmon from road to sea.

Some challenges with a case study approach is whether to focus on one case or multiple cases. More observed chases means often that the depth of each case will be less detailed (Creswell 2007). For this thesis, the focus is only on the Hav Line method.

2.2 Data sources

This subchapter of the thesis is separated into two parts, which should give the reader an overview over the data sources collected and used for both the qualitative research and the quantitative research.

As a summary, the sources of data that is used for this thesis is based on different literature sources and conversations with professionals in these areas. Relevant literature includes scientific journals, articles and previously conducted research papers on this topic. The theoretical disciplines encompass supply chain management, transport management, maritime science related to seafood industry and environmental science.

2.2.1 Qualitative data sources

A lot of the information was obtained from online research linked to the Norwegian aquaculture industry, Hav Line Gruppen AS and the Hav Line method. This provided the information about the market and the main players in the salmon farming industry. The information obtained from the data collections and conversations helped to obtain important information around the theme of fresh farmed salmon production in Norway. A lot of the information that has been obtained, came from the literature review and the application document for a subsidy that Hav Line Gruppen AS submitted to the Norwegian Coastal Administration.

During the work with the theoretical part of the thesis, Haugland Gruppen AS and Sekkingstad AS were contacted for information about the Hav Line method. Carl-Erik Arnesen, CEO of Hav Line Gruppen AS, was the main contact person within the company. The correspondence has been done through email. In the first mail received from him, a presentation for "Enovakonferansen 2018" (Enova Conference 2018) was obtained. This presentation contained i.e. information about the Hav Line method, facts about the new vessel, the cooling processes and the downstream wastewater process.

Harald Hjelle, supervisor for this thesis, provided the contact information for Dag Robert Bjørshol, who is responsible for the project "transPORT2050" in the municipality of Hitra. He provided us with the latest report written about this project, which concerns the reallocation of freight flows to sea transport from central Norway. This correspondence was done through email. This can be an example for secondary data. Secondary data is what is collected for other purposes, for instance research on the topic that has been conducted so far and relevant theories. Secondary data can also be gathered through a conventional literature review.

2.2.2 Quantitative data sources

The data that has been gathered for the purpose to compare the Hav Line method and the business-as-usual transport in a quantitative way, are the transport distances for all transport alternatives, specifications about the Hav Line vessel and the other applied means of transportation for the intermodal transport alternatives.

Primary data for this part of the thesis was collected by contacting Hav Line Gruppen AS, regarding the new vessel. The obtained data from the company about the project is the foundation for the analysis and comparison that was be conducted. Examples to gather this data are conversations with personnel from Hav Line Gruppen AS involved in the project or through provided documents. As for the qualitative data sources, much of the needed quantitative data could be obtained from the application document for a subsidy of the Hav Line method from the Norwegian Coastal Administration and the presentation from the Enova Conference 2018.

Especially four papers are important for the quantitative part of this thesis. From Thune-Larsen et al. (2014), information about the socio-economic costs of road transport is obtained and from Rødseth et al. (2017) emission factors for sea transport are obtained. Other values for calculations come from the papers Hjelle (2011) and Hjelle and Friedell (2012). These values are introduced more detailed in Chapter 7.0.

2.3 Summary of the methodology

For the methodology, a qualitative and a quantitative research approach is used. In other words, this approach is called a mixed method. The qualitative research approach is used for gathering information around the topic of the thesis, while the quantitative research approach is used to gather data for the calculations of emissions and socio-economic cost associated with transport of fresh farmed salmon from Norway to Denmark. Including to this, a case study approach is used to observe the specific case of the Hav Line method.

Some of the data sources collected, have been used for both the qualitative and quantitative research approach, as i.e. the application for the subsidy that Hav Line Gruppen AS sent to the Norwegian Coastal Administration and the presentation from the Enova Conference 2018. Other sources have solely been used for one of the research approaches. An example are data sources for the quantitative research approach, where several reports from TØI has been used to obtain factors for the evaluation. For the qualitative research approach, this were mostly the mentioned sources in the theory chapters.

The gathered information provided the basis for the conduction of the study for the transport of fresh farmed salmon from Norway to Europe.

3.0 Relevant theory

After introducing the reader to the relevance of the research topic and the chosen methodology, Chapter 3.0 presents the relevant theory behind this thesis. The first subchapter deals with the environmental impacts of traffic and relates the concept of sustainability to it. It is also explained why more sustainability is needed within the transport sector.

The next subchapter introduces the reader to the issue of external effects of road traffic and the there out resulting socio-economic costs. Chapter 3.3 shows how value is created through transportation and links this theory to the observed case in this thesis. The last part of this chapter explains the theory behind the SWOT analysis. A summary of the relevant theory is provided at the end of this chapter.

3.1 Sustainability and the impact of transport on the environment

Environmental protection and a sustainable use of resources are nowadays important issues for our society. The topic is regularly a part of political discussions and there out resulting laws and regulations, well represented in the media and an essential part of many company-intern guidelines.

When it comes to environmental pollution, one cannot ignore the transport sector and its negative impacts. Almost a quarter of the totally emitted GHG in 2015 in the EU were caused by transport, as shown as in Figure 1, which also represents an increase from “just” 15% in 1990 (Eurostat 2017). This value is going to further increase since the demand for transport keeps on growing, due to effects such as globalization and population growth in almost all parts of the world. The purpose of this chapter is to show the environmental impacts of transport and explains why new transport solutions have to perform well in other areas than just environmental compatibility in order to be truly sustainable in the long term.

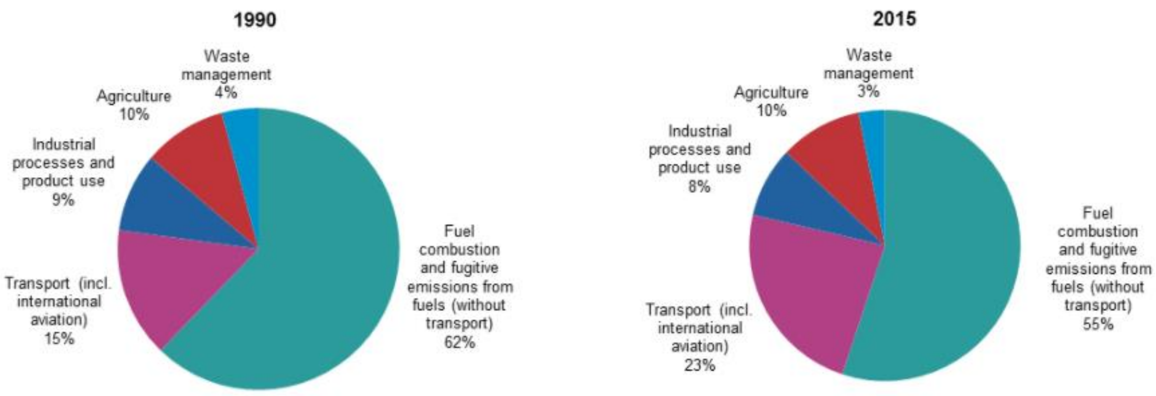


Figure 1: GHG emissions caused by sector in the EU (Eurostat 2015).

It is a proven fact that transport has a large impact on our environment. The numbers in Figure 1 verify this statement. However, it is often not that easy to measure all of these impacts and further on even more difficult to mitigate them. The relation between transport and the environment can be seen as complex. On one hand, transport provides many socio-economic benefits for the society, most notably mobility, which is crucial for individuals as well as every economy. On the other hand, transport is also a responsible for negative impacts on the environment, which lead among other things to socio-economic costs, a concept which is described in detail in the Chapter 3.2. Impacts on the environment can be basically separated into three categories. Direct impacts are the immediate consequences and are often clearly understood due to their cause and effect relationships. Examples here are noise pollution or accidents. Indirect impacts usually have more severe consequences and the coherence between causes and effects is more difficult to perceive. An example for indirect impacts might be the relationship between particle emissions in urban areas and their connection to cardiovascular problems. The last category concerns cumulative impacts, which takes the effects of both of the afore-mentioned categories into consideration and examines their impacts on ecosystems. Cumulative impacts are often extremely complex in their nature. Climate change can be seen as an example, since it is based on a number of causes from different sources (Rodrigue 2017).

Some specific problems that are caused by transportation are mentioned in the following paragraphs. The mentioned examples are either linked to road or sea transportation, since these two types are the relevant transportation modes for this thesis.

The perhaps most notable problem related to the issue of environmental impacts through transport is air pollution. Road vehicles as well as marine engines used in vessels are sources of pollutants such as gas (i.e. CO_2, NO_X or SO_X) and fine particles (i.e. ash and dust). These often toxic emissions are linked to a number of health issues and partly also to climate change. A special form of air pollution which is often found around urban areas is smog. Smog is mixture of fog and particles emitted by vehicles, mostly road vehicles in this case, but also by other industry sectors and private households. Besides the impacts on human health, smog can be also held responsible for local meteorological conditions. The combustion of fossil fuels plays a major in the emergence of air pollution (Rodrigue 2017).

Two major issues that are associated with sea transport are the already mentioned emission to air and discharges to the sea. Types of discharges to the sea can be summarized under oil pollution, wastewater, antifouling paint, ballast water and other waste materials. Oil pollution can emerge through either larger accidents, which are rare in occurrence but can have major impacts or through smaller incidents like continuous leakages of small amounts of oil and lubricants. Wastewater from vessels is often in comparison to wastewater from on land facilities not handled and processed by respective systems. Ballast water can often contain organisms, which can cause problems to local ecosystems when discharged on sea or in ports (Lindgren et al. 2016). The limited ability of storage space for trash and garbage on vessels often leads to the direct disposal on sea. Figure 2 illustrates the impacts of vessels on the environment.

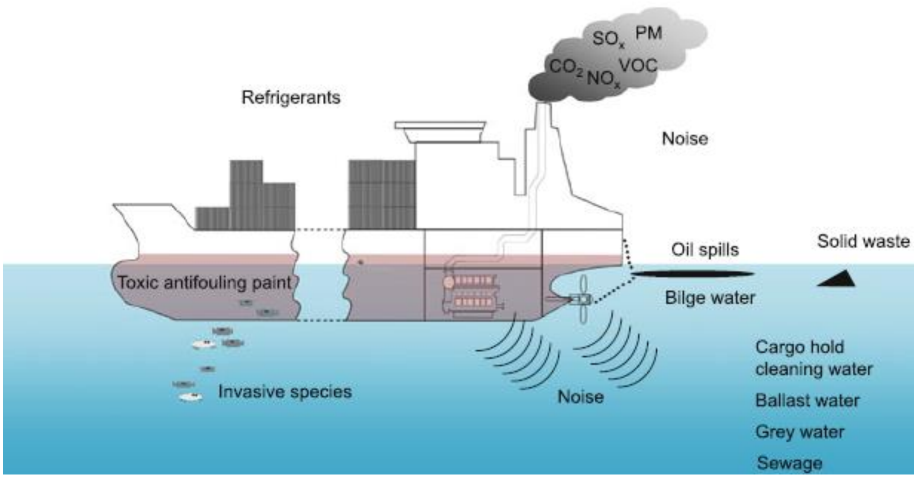


Figure 2: Environmental impacts of vessels (Andersson et al. 2016).

A further issue related to transport and its negative impact is noise. Noise is described as an irregular and disturbing sound that affects humans as well as animals. Long-term exposure to high noise levels (> 75 dB) can have serious impacts on the wellbeing of influenced individuals. Noise impacts of sea transport are often more local and concentrated around port areas. Hence, it might be easier to mitigate the impact. The noise impacts of road transport are more spread due to wide-spanning road networks and hence it is more difficult to overcome them (Rodrigue 2017).

The networks and facilities that are required for transport processes have a direct impact on the landscape by so-called land take. Ports, depending on their size, might require significant changes of their environment, but the impact of land take or use is rather local and pertains a specific area. Road transport networks might not be as burdensome as port facilities with regard to the used space at one location but are more widespread due to the characteristics of the transport mode. This leads to a high number of facilities and of course thousands of km of roads across landscapes. Further impacts through land use might pertain the soil quality and biodiversity (Rodrigue 2017).

3.1.1 Sustainability

The concept of sustainability has become an important dimension of transportation and focuses on a wide range of objectives, from operational aspects like the emissions of vehicles to strategic alignments like entire "green" supply chains (Rodrigue 2017). Thereby, the term sustainability is commonly linked to environmental friendliness, which is without doubt one important factor of this concept, but not the only one. Typical examples that are associated with it, are for instance non-fossil fuel powered vehicles, "green" urban areas, animal-friendly farming, the application of alternative technologies for energy generation and so on. It can be said, that the usage of the sustainability concept became quite popular in the most recent decade and it is nowadays used by many organizations, whereby this might be also linked to the good marketing potential of the sole usage of the term.

However, if we take a look on one of the original definitions, made by the World Commission on Environment and Development in 1987, which describes sustainability as a way of utilizing resources in such a manner, that the present needs can be met without constraining the needs of future generations, we can see that the concept encompasses more than just environmental friendliness and can be interpreted in several ways

(Ahi/Searcy 2013). It is difficult to find a consensus in the academical world that sets a clear boundary of what should be seen as a part of the sustainability concept and what should be excluded.

The triple bottom line

Ahi and Searcy (2013) conducted a comparative literature analysis of the definition of sustainable supply chain management and indicate there, that the term sustainability can be found in a variety of coherences, from philosophical positions to multi-dimensional applications for business management. They also found out, that the concept moved away from its early incentive, which mostly promoted the above-mentioned focus on environmental issues and is increasingly moving towards a so-called “triple bottom line”. This approach encompasses a further focus on the economic and social sustainability dimensions besides the already mentioned environmental one (Ahi/Searcy 2013). A similar description for “corporate sustainability” can be found in a paper composed by Amini and Bienstock (2014). Their literature review showed among other definitions, a “triple bottom line” approach defined by Elkington, which describes corporate sustainability and includes again the three factors of social, environmental and economic sustainability (Amini/Bienstock 2014).

Generally speaking, there are many different academic definitions of the term or concept. The already mentioned paper of Ahi and Searcy (2013) provides the reader with a solid review over a number of academic sources that defined sustainability, starting from the year of 1992 to 2012. The different definitions were compared by using seven evaluation factors, namely economic-, environmental-, social-, stakeholder-, volunteer-, resilience-, and long-term focuses. Out of the eight reviewed definitions, seven included at least the aspects of economic-, environmental- and social focus, but varied among the other criteria. The fourth most common accordance among the sources pertained the focus on a long-term horizon. Only one reviewed definition didn’t take the approach of economic, environmental and social focus, by putting the emphasis on solely stakeholder- and long-term considerations (Ahi/Searcy 2013). This roundup and comparison of several definitions showed that there are some dissensions about the term in the literature, but also accordance, especially on the mentioned triple bottom line approach.

Therefore, the mentioned triple bottom line approach for sustainability is the chosen definition of the concept for this thesis. This approach states basically, that an organization has to pay attention to all three dimensions of sustainability, in order to be truly sustainable in the long term. Furthermore, it was also stated by Elkington that the three dimensions are interrelated and can have an impact on each other. For instance, a corporation will find difficulties to be successful in the long term, if it is just focused on a one-dimensional short-term target, let's say sole financial success (Amini/Bienstock 2014). A pure focus on financial measures like revenue or profit, might lead to a situation where employees are unsatisfied or even endangered due to missing measures for safety at work, hence this organization wouldn't be considered as socially responsible. A similar example could be drafted related to a situation where the environment in which an organization is acting takes harm, due to this one-sided emphasis. Therefore, it is necessary that corporations keep all three factors in mind and consider possible trade-offs between them.

The need for more sustainability in the transport sector

The link between the just explained sustainability concept and traffic or more specifically freight transport, lies behind the current worldwide developments. Consumer demand is steadily growing and leads in combination with globalization to an exponential growth in freight and corresponding flows. Due to that, it has become indispensable for many countries to analyze these flows and aim for improvements, without interfering trade (Ganji et al. 2012). A suitable example for this demand grow, is the export of Norwegian seafood products. The numbers have been increasing over the last couple of years and it currently seems like that one record year follows the next one. For instance, Norway exported a record high of 2.6 million tons of seafood in 2017. This number represents a 7% increase in volume compared to 2016. The exports of salmon made up for slightly more than one million tons out this volume (Norwegian Seafood Council 2018b). In addition to these already impressive numbers, it is predicted that the demand will further grow in the next years, which should even lead to more constraints on the Norwegian road network.

In the context of sustainability and freight transport, it should be mentioned that the movement of goods is usually one of the major sources of exhaust emissions like CO_2 i.e. or other negative effects, i.e. noise and accidents. The "Intergovernmental Panel on Climate Change" (IPCC) estimates for instance that approximately 10% to 15% of the worldwide energy related emissions are caused by transport (IPCC 2014). The high number depends thereby on one hand on the fossil fuel dependence of the sector and on the other hand on the intense energy needs. The last couple of years showed a sign of more awareness for this issue, but there is still much to do, in order to “clean” this sector up (McKinnon et al. 2014).

This is further on also were a connection between the concept of sustainability and alternative transport solutions for fresh salmon from Norway to the European continent can be seen. A new method, no matter which one, has to make sense on several dimensions in order to be successful and applicable in the long term. There are probably for instance a certain number of technological solutions that could be used as an alternative to common road transport. Even though, these solutions might be for example more environmental friendly than conventional trucks, this does not automatically mean that they are applicable for the involved parties. A sustainable long-term solution has to meet other criteria, in this case most likely business-related ones, otherwise there wouldn’t be any intention for corporations to consider a change.

3.2 External effects of road traffic

The EU-28 modal split for inland freight transport shows unsurprisingly that road transport is the dominant choice when comes to the selection of a transport mode. Around 75% of the total ton-km were transported on the road from 2010 to 2015 in the EU (Eurostat 2017). The European Union has strong intentions to achieve a shift of the modal split and reach a more balanced result, in order to lower emissions and other negative impacts that are today mostly caused by road traffic in the freight transport sector (European Commission 2011). This goal is also valid for Norway, even though not a member of the EU. The Norwegian government issued the NTP, which includes among other goals, that the country’s freight transport sector should become more efficient, safe and environmental friendly. A part of the strategy in order to achieve these objectives, is to shift more freight flows from the road to the modes of sea and rail transportation (National Transport Plan 2016). It should be also mentioned here, that there are also a number of negative side effects linked to other transport modes than road. Trains and aircrafts respectively railway stations and airports are typical sources of noise pollution for immediate bordering areas and sea transport, especially large vessels used in oversea trade, are contributing to air pollution by emitting large amounts SO_2 through the usage of bunker oil as fuel. However, measured by the total share of damages caused by traffic, road transport is the worst due to its widespread usage (CE Delft 2007).

There might be several reasons why road transport is such a popular choice, which will be explained later, but two of the perhaps most important criteria are the total costs for a transport operation and the flexibility of the mode itself. This was also shown by the results of a survey, which suggested that price factors are more important for Norwegian exporters than other transport selection related criteria (Pedersen/Gray 1998). Road transport is distinguished by high flexibility and enables door-to-door deliveries. Further on, initial investments are not as high as for other transport modes, which usually require dedicated assets like transshipment terminals i.e. Due to this situation, road transport is often the cheapest option for cargo owners in practice, even though road transport doesn't have the lowest transport costs when measured in price per ton-km transported (Grønland 2011).

Even though it cannot be denied that transport is a crucial driving force for economic growth, it is also clear that there are negative aspects associated to it. Transport is accountable for many different types of emissions that pollute the air, for instance carbon dioxide, sulphur dioxide or fine particles (Friedrich/Bickel 2013). Emissions or air pollution are probably the major negative impacts that are linked to transport or traffic by the society, due to the raised awareness for climate change. But transport is also accountable for other, often local damages. Typical examples here for would be noise pollution, traffic congestions and -jams, accidents, road wearing etc. Usually, damages like these and emissions are not appropriately reflected in transport prices and summarized under the term of "external effects" or "- costs" of transportation (Friedrich/Bickel 2013).

External effects are caused by parties that conduct transport operations, i.e. a freight forwarder or in a broader sense the cargo owner, but the resulting damages on human health, flora, fauna and materials are not covered by them. Instead, those damages are paid by third parties that had initially nothing to do with the actual transport activity (Friedrich/Bickel 2013). Therefore, external effects are the cause for costs, that are carried by the society or taxpayers, which is obviously a problem. Reasons for external costs are often linked to non-optimal choices from society's point of view regarding freight transport, like the number and destinations of trips, the selection of less adverse transport modes or wrong infrastructure investment decisions, since individuals as well as organizations usually tend to select the cheapest transport solution in the short term. Thereby, external effects or costs are often left out of the consideration, due to a missing long-term perspective. A suitable example here for, is that road transport is still the by far most dominate choice for transport operations within Europe, way ahead of any other transport modes. However, non-optimal resource allocation associated with freight transport, usually leads to welfare losses for the society in the form of external or socio-economic costs (Friedrich/Bickel 2013).

A more formal definition for external costs separates costs associated to transport into two categories, namely social costs and private costs. The first mentioned reflect costs for the society that occur for instance while using infrastructure, which might be wear and tear or capital costs and other types of costs for accidents, congestion and environment. Private costs encompass everything directly borne by the user, i.e. energy costs, wear and tear on the vehicle, insurance, acquisition costs, etc. The difference between those two cost types are then external costs. This definition is based on the economic welfare theory, which suggests here that transport users should pay for all arising marginal social costs that are created by their transport processes. Hence, optimal charges and fees for infrastructure usage should represent these marginal social costs (CE Delft 2007).

In order to avoid these welfare losses, policy makers like the EU or the Norwegian government are currently aiming to internalize external effects. The process of internalizing external effects means that resulting costs are virtually paid by the causer, so that the effects or costs become a part of the decision-making process, when it comes to the selection of a suitable transport operation. Such an internalization can be reached by applying to ways, firstly through direct regulation, i.e. prohibitive rules like a ban of fossil fuel powered cars, or secondly by using indirect measures like market-based instruments that provide incentives to choose the desired solutions. Examples here for might be special taxes, charges, tolls, but also subsidies (CE Delft 2007).

3.3 Value creation through transport

The term value can have different meanings, depending on the used perspective. Iyer (2009) for instance, states that there are basically two options. Option one is that value is defined by customers, who are possessing the economic power to make a choice of acquiring or not acquiring. The second option would be that value is specified by producers, who have the power to determine the characteristics of a product or service that customers are willing to pay for. Further, it is possible to use the term for subjective specifications, which are difficult to quantify and depend on individual opinions, or for objective specifications that can be measured and quantified (Iyer 2009).

The concept of value creation is used in this thesis to show how value is created or added through transportation in a supply chain for fresh farmed salmon. Generally speaking, the most obvious value adding function of transport is to transform the geographical location of a good and transfer it from a certain “source” or the point of production to the “drain” or the point of consumption. Simplified, this means more or less to transport a product or service over a certain distance, from a producer to a customer. Transport is the link between a number of different stages in every supply or value chain. This is not different in the case of fresh farmed salmon transport from Norway to Europe. Salmon breeders and processors in Norway act as the point of production. Wholesalers, retail chains or maybe even private individuals in mainland Europe act as the point of consumption. Transport enables salmon producers to deliver their goods to their customers, the customers on the other hand have the opportunity to receive and consume the salmon.

However, like with almost any other operation within a value chain, each activity can contribute more or less to the final value of a good. Often, there is a certain room for improvements and optimization. A typical example from the salmon farming industry might be the feeding process, whereby better fish food might lead to a higher quality of the final product, hence a higher price on the market. Transport can also play a crucial role here and the applied transport method can affect the final product in either a positive or negative matter. Larsen (2003) discusses the issue of value creation with regard to the transportation of seafood products.

In a TØI-report about value creation in fish transports (Larsen 2003), a practical definition of the concept of increased value creation in the fishing industry through transport is introduced, namely that cargo carriers can help to raise the final value of seafood products by offering high quality transport services. They can for instance contribute to the product quality, if the goods are transported in a fast manner and handled appropriately while in transit. This pertains especially the cooling process in seafood value chain. Further, they can also help to lower costs for the transported goods. On a business scale, this would be for instance the transportation of large volumes of consolidated cargo in order to reduce the transport costs per ton i.e. On a larger scale, carriers could apply more environmental friendly alternatives, which would lead to less of the negative aspects from the afore-mentioned chapters, like environmental pollution and socio-economic costs, which would further on mean, lower expenses for the society. More examples for value adding through transport might be the reduction of idle time, more flexibility, comprehensive flow of information to members in the value chain, etc. (Larsen 2003).

A new alternative for the transport of fresh farmed salmon from Norway to Europe could fulfil some of these factors and add more value to the final product. Chapter 6.0 includes a comparison of a standard business-as-usual transport chain from a producer in Norway to Europe and the new Hav Line method. The evaluation of the new sea transport solution will also show how transport and logistics add value for the customers/society and/or the companies in this case. For the “single” customer it will finally most likely not matter which mode of transport is applied. However, if the transport process can add value in such a way that the end product is noticeably better or cheaper, it might even influence the customer’s opinion. It is expected that a shift to sea transport will lead to some kind of value creation, i.e. lower emissions or less of the negative road freight traffic related issues, hence fewer socio-economic costs.

Conclusively, it should be mentioned that freight transport can be seen as the fuel of a prosperous economy and the strategic link between a number of local and global value chains. In a globalized world, transportation can be one of the corner stones for even small countries to develop specialized and productive industry sectors and link them to worldwide production networks. New efficient transport solution can be central to national productivity and value creation (National Transport Plan 2015).

3.4 SWOT analysis

The SWOT analysis is a strategic analysis that traditionally is most used by organizations to get an overview of both the external and internal factors. "Under the SWOT approach an attempt is made to establish what has to be done to maintain the satisfactory things and correct the faults, to ensure that opportunities are exploited, and threats avoided or reduced in impact" (Hussey 1998, p. 167). The SWOT analysis can also be used to more specific analysis, in other fields like i.e. research and projects. It consists of four elements. The first two elements are the organizations strengths and weaknesses, while the two last elements are the opportunities and the threats that they face. The analysis can give a solid foundation for decision-making processes and can be used as a tool for identifying areas for improvement and to reveal the competitive advantages that are present.

In a competitive setting, strengths are the advantages that organizations have, compared to other organizations or solutions. The strengths are internal advantages, so in other words the possibilities the organization or solution possess for themselves. One way to keep an eye on the strengths is to have regular contact with i.e. customers and suppliers.

Weaknesses is everything the organization or solution is worse at, compared to i.e. competitors, trends in the market and customer´s expectations. The weaknesses need to be analyzed, so that they does not cause any more disadvantages than necessary. Weaknesses are internal elements, which are problems that the organization or solution can control by themselves. However, weaknesses can often be ignored. The SWOT analysis is a tool that can help bring the weaknesses forward, so that the underlying cause can be dealt with.

Possibilities can be looked on as opportunities. These opportunities can come from a need in the market, where the current solution does not satisfy this need. This need in the market is the possibility that the organization can take advantage of.

Threats can come from many sources among the environment. The most normal threat comes from the organization´s or solution´s biggest competitor. Other sources for threats can i.e. be trends, legislations or environmental cases. The threats are external problems that can´t be ruled over, but it´s important to at least monitor them.

In the context for this thesis, the SWOT analysis provides an overview over sea transport in general and can help to compare it against business-as-usual transport. The overview over this gives a simple description of the characteristics, especially for sea transport, that can be used further on in the thesis.

3.5 Summary of the relevant theory

The relevant theory is based on four different issues, which are necessary as the framework for this thesis. These four topics, which are presented in separate subchapters, are the impact of transport on the environment and sustainability, external effects of road traffic, value creation through transport and the SWOT analysis.

It was shown that transport has a large number of different impacts on the environment. Sometimes it can be challenging to estimate the effects of these impacts and select the right measures to avoid them. A typical example here for are i.e. GHG emissions and their relation to climate change. However, it is clear that the environmental damages caused by the transport sector are a problem for the society. The sector and corresponding negative impacts have grown over the last decades and this trend is going to continue, if no changes are made. Road transport is perhaps the mode of transportation with the most significant associated negative impacts, see socio-economic costs. Therefore, it would be desirable to achieve a shift of transport flows from road to transport to other modes. Other modes can be without doubt, not regarded as perfect in every sense, but if they are used in an optimal way, they can help to solve some of the issues that are related to the sector. Furthermore, it was also explained why new transport solutions have to be sustainable in more the one area. Even though, environmental protection as an important issue, environmental friendliness should not be the only considered aspect in this context. It also important for new solution to make sense in an economical perspective, otherwise they won't be sustainable in a long-term.

Transport is the link between different stages in supply chains. This is also valid for the Norwegian aquaculture industry. Transport has contributed to the possibility for farmed Norwegian salmon to become one of the biggest players in the market today, because of the possibility to transport it to different countries. Including to this, transport can contribute to i.e. an increase of the quality of fresh salmon. The quality can be increased, if the freight is transported in a fast manner and handled appropriately while in transit.

4.0 A comparison of road and sea transport

Transport can be simply defined as a process where either passengers or freight is moved from one place to another, as mentioned in the previous chapter. However, there are different ways or modes of transportation, each with distinct characteristics and advantages as well as disadvantages. The basic distinction can be made between the three main transport modes land, sea and air and further on eventually between modes like pipeline-, cable- or space transport (Rodrigue 2006). An important major distinction for on-land transportation can be made between transports conducted on roads with different vehicles or on railways by using trains. The choice of a transport mode can depend on several factors and is often depended on the goods to be transported and their specific requirements. The following paragraphs contain a short description of the different transport modes, in order to provide the reader with an overview. Later on, there is a stronger focus on the comparison of sea and road transport, which are the relevant modes for this thesis.

4.1 Air transport

When it comes to lead time, air transport is the clear winner compared to other transport modes. As the fastest mode, it is usually utilized for high-value/low-volume goods, just-in-time inventory replenishment or emergency cases, i.e. situations where spare parts are urgently needed. A further good example for the usage of air transport are perishable goods, such as flowers or food. Therefore, air transport is also used for the export of fresh salmon from Norway, but not necessarily to Europe, rather to Asia and North America. The speed of this transport mode comes at a certain price and there are further disadvantages besides this high-priced character. Air transport emits the largest amount of pollutants per ton transported goods and requires a specific network, made up of airports, which reduces transport flexibility. Due to this reduced flexibility, air transport is usually combined with another transport mode in practice, i.e. road transport for the pre- and post-carriage (Carnarius 2018). Gourdin (2006, p. 93) summarizes it as follows, “Air transport is often viewed as a premium, emergency-type service that is used when all else fails. The most expensive of the modes, airfreight offers the logistics manager fast, on-time service, but at a relatively high price”.

4.2 Rail transport

Rail transport is one of the two major on-land transport modes and often seen as a cost-efficient and environmental friendly solution for cargo transport over distances longer than 400 km. Trains typically use less fuel or energy per ton of cargo transported than cars or trucks and of course airplanes. Railroad transport is often associated with bulk cargo, such as coal, iron ore or grain. However, trains can be also utilized for the transit of containers and are capable of transporting high capacities when double stacked. One of the limiting factors of rail transportation is similar to the aforementioned mode of air transport, namely reduced flexibility. Trains need railroads and a respective network of railway stations or at least facilities that can be used as transshipment points. Unless a user doesn't operate such a transshipment facility on-site, road transport is needed for pre- and post-carriage (Carnarius 2018). Gourdin (2006, p. 89) defines it as follows, "Railroads offer the logistics manager cost-effective, energy efficient transport of large quantities of goods over long distances. Though often associated with the movement of low-value/high-volume cargo like coal, railroads can also move a large number of containers in intermodal movements". The geography of Norway is an obstacle when it comes to transportation of fresh salmon from the farms to end markets by using rail transport. The infrastructure of the rail network is not dense enough and many salmon farms/processing sites find it challenging to connect with the railway network from their respective locations.

4.3 Road transport

The most common form of transportation within the EEA is road transport. Road transport, which is usually conducted by using different sized HGVs, offers many advantages and is often seen as the most practical and economical solution for transport operations within the European continent. The perhaps most outstanding advantage of this transport mode is the given flexibility and versatility compared to other modes. The road network, which is utilized by trucks, is far reaching in Europe and denser than any other transport infrastructure network for other modes like railway-, inland marine- or air transport. Due to the existence of this extensive road network and the fact that there are more or less no technical obstacles for trucks, like i.e. the barriers for interoperability in the railway sector, it is basically possible to conduct any transport operation directly from one random destination in Europe to another. Furthermore, it is usually uncomplicated to cross borders and the liberalization of the sector led to fierce competition among actors. The implemented liberalization of the road transport sector in Europe allowed among other things, cabotage. Due to the allowance of cabotage, it is possible for freight forwarders from countries with low labor costs and other non-wage costs to operate in countries with higher cost structures, which generally led to the availability of relatively cheap road transport all over Europe.

All of these reasons make road transport a cost-efficient solution, which is often the preferred choice of cargo owners when it comes to transport (Fremont/Franc 2010). Road transport is the currently most utilized transport mode for the export of fresh farmed salmon from Norway to Europe. Door-to-door deliveries allow an unbroken cold-chain during transport and generally offer a high degree of flexibility. Salmon farms are often located in rather remote coastal areas, which hands road transport another advantage compared to other modes, since farms can be reached in a far easier manner and further transshipment processes are redundant when the goods are only transported by one mode.

However, even though there are arguably a lot of advantages when it comes to road transport, there are also disadvantages. From the perspective of a shipper, one of the biggest limitations is obviously the rather low carrying capacity in comparison to other modes. If volumes are large enough and distances are longer than 400 kilometers, it is perhaps more economical to use either sea- or railway transport. The limited capacity of trucks can lead to high costs per ton-km (Carnarius 2018). But the perhaps most negative aspect of road transport is the negative impact on the environment. An increase for transport demand over the last decades and the availability of relatively cheap road transport services combined with a well-functioning infrastructure network, has led to a strong growth in freight transported via road (Fremont/Franc 2010). Figure 3 illustrates a comparison of typical CO_2 emissions between transport modes and clearly shows the huge impact of road transport, beside air transport. HGVs are emitting usually more CO_2 per ton-km than railway- or sea transport. Additionally, road transport is also responsible for other negative impacts on the society, see the aforementioned external effects. Overall, it cannot be said that road transport is the only environmentally harmful transport mode, but it is in many cases a worse choice than its alternatives.

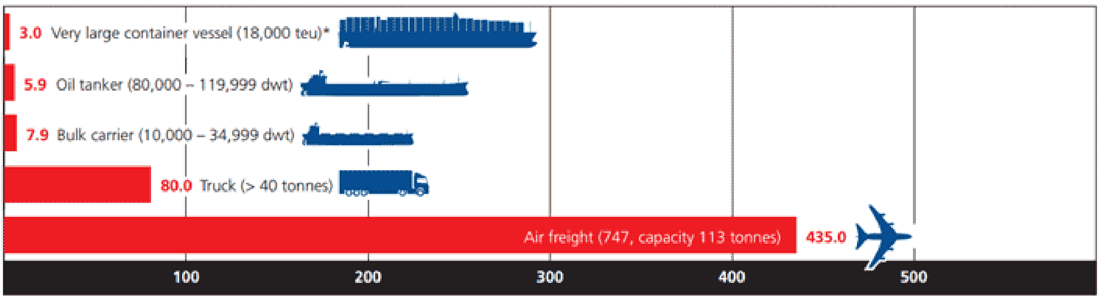


Figure 3: Comparison of typical CO_2 emissions between modes of transportation (Green Supply Chain 2016).

4.4 Sea transport

The last remaining mode of transportation is sea transport, which can be separated into maritime shipping and inland navigation, whereby the lastly mentioned is carried out on inland waters, like rivers and lakes. On a worldwide scale, seaborne trade accounts for approximately 90% of the goods transported measured by volume and can be hence seen as one of the main drivers for global trade. Maritime shipping can be further divided into either deep-sea navigation, which pertains transports that cross the oceans or short sea shipping (SSS), which is conducted in coastal areas by smaller ships. Depending on the used type of ship, transported goods and organizational form, there are further distinctions for sea transport. The most common distinction for vessel types are bulk carriers for crude oil, iron ore, grain, etc. container vessels and specialized vessels for specific cargo types lie cars, chemicals or refrigerated cargo. Organizational wise, shipping services can be divided into liner services, which have typically a regular set of routes and schedules and charter services, which vary between serviced routes from order to order. Ocean freight services are usually less expensive than other transport modes and mostly used for the transshipment of low-value/high-volume products (Carnarius 2018).

A huge benefit besides the high cost-efficiency of sea transport, it is the cheapest of all transport modes, is the high loading capacity. No other transport mode can carry as much cargo as sea shipping services. Due to this, it is an outstanding choice for transport operations over long distances, as long as there is no urgent need for the transported goods, due to its relatively slow transport speed. It is also considered as the most environmental friendly mode of transport, measured by the caused emissions per transported ton. There are however deficits regarding flexibility, like for the aforementioned modes of air- and railway transport. Sea transport requires certain facilities for transshipment processes between sea and land, usually some type of crane(s) located in ports and road transport is often a part of transport chains that include sea transport for the purpose of pre- and post-carriage.

In this thesis, the sea transport route of interest is located between Norway and Denmark. SSS is already used for the transport of fish, but usually for canned or frozen products, not fresh fish, which has different requirements regarding lead time and temperature conditions during transport.

Figure 4 gives an overview for each transport mode, including intermodal transport, and the characteristics that they provide when transporting freight. The comparison uses characteristics as if the transport distance is less or more than 400 km, if the freight they transport is oversize or heavy loads, if it can carry freight with special requirements, if the transport mode can cross borders and/or overseas. Sea transport along with intermodal transport fulfills most of the categories and is usually only not suitable for short distances under 400 km.

FREIGHT HUB	Distance less than 400km	Distance more than 400km	Oversize or heavy loads	Special requirements (hazmat, refrigerated etc.)	Cross-border	Overseas
		●	●	●	●	●
		●		●	●	●
		●	●	●	●	
	●			●	●	
		●	●	●	●	●

Figure 4: Comparison of transport modes (Carnarius 2018).

4.5 SWOT analysis of sea transport as an alternative for export of fresh farmed salmon from Norway to Europe

This thesis focuses on the shift of transport streams for fresh farmed salmon from road to sea. Therefore, the following SWOT analysis will put an emphasis on sea transport and compare its strengths and weaknesses, as well as existing opportunities and possible threats against road transport. As already mentioned, road transport is the dominant choice for exports of fresh salmon to Europe. The SWOT analysis uses a number of assessment criteria for the comparison of the two modes as a basis. The considered criteria are the following:

- Transport speed.
- Reliability of the used transport mode.
- Transport cost.
- Environmental impact.
- Safety.
- Flexibility of the used transport mode.

4.5.1 Strengths

One of the perhaps biggest advantages of sea transport compared to any other transport mode is the high carrying or loading capacity at low costs. Transport vessels are often distinguished by low operating costs, which is a result of their ability to carry large volumes and have a small energy consumption in proportion to their transported volumes. Further on, vessels also have limited work force requirements, which contributes to the fact that sea transport is often classified as the cheapest transport mode (Rodrigue/Comtois/Slack 2006).

Vessels exploit water routes as their transport medium. One big advantage of this medium is the widespread natural availability of it around the globe and the fact that water routes are often accessible at no costs. There might be exceptions where vessels have to pay for the usage of certain water route sections, i.e. due to tolls for infrastructure use or environmental taxes, but the usage costs are normally below the ones for the usage of a road network (Rodrigue/Comtois/Slack 2006). Water routes or at least large sections are located in the open sea, which means no direct impacts on residents, whereas roads usually cross villages and towns at some points. Especially Norway with its long coastline and hundreds of fjords has the possibility to take advantage of water as a transport medium, due to the easy accessibility. Considering advantages for the public, it is clear that the maintenance of a road network requires more public funding than a water route along the coastline.

Sea transport can be also seen as a safe mode of transport. Necessary requirements regarding safety conditions on-board of a vessel are often higher than for road transport vehicles. This leads to fewer accidents and reduces related costs. Regarding road transport, Langeland and Philips (2016) state that Norway has about 35% more deaths in accidents involving heavy goods vehicles per capita than the average in Europe. This indicates that the road transport network in Norway is not necessarily equipped for large amounts of HGV-transported value streams, especially on the West Coast and in Northern parts of the country, which are important regions for the salmon farming industry (Langeland and Philips 2016).

Furthermore, sea transport is also considered as a “cleaner” transport mode than road transport. This statement depends of course on the used and compared scenarios, which might vary in used technology (i.e. old vs. new engines), fuels (i.e. low-grade bunker fuel vs. conventional diesel) or the type of observed emissions, just to mention a few examples. However, one specific pollutant has attracted a lot of attention from researchers and the media, namely CO_2. CO_2 emissions are one of the main drivers, that are made responsible for climate change and transport is characterized as one of the main causers for it, regardless if we talk about passenger or freight transport. A good way of measuring the environmental friendliness of a transport mode is to look at the caused amount of emissions (grams of CO_2) per ton-km, since it puts the comparison for every mode into the same proportion. Figure 5 shows a certain range for this CO_2 emission values for each of the four major transport modes and clearly depicts that shipping is the most efficient and environmental friendly mode in this case (International Energy Agency 2009).

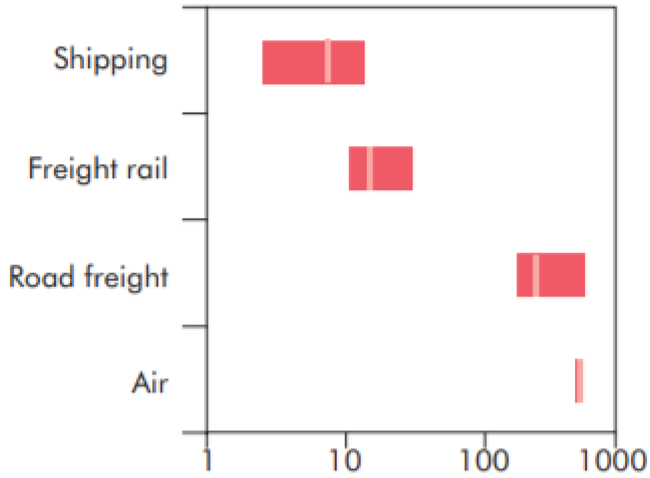


Figure 5: Efficiency of transport modes measured by CO_2 emissions per ton-km (International Energy Agency 2009).

4.5.2 Weaknesses

When it comes to the used infrastructure network, vessels usually require nothing similar to roads like trucks, but they need at least some sort of facilities that can fulfil their function as transshipment points. These points or facilities are usually found in ports or eventually on-site of a cargo owner's facility. Ports enable among other tasks, the transition of goods from sea to land and vice versa, as well as the connection to the hinterland. The need of vessels for these transshipment points reduces the flexibility of sea transport. Furthermore, door-to-door deliveries are rather unusual with this mode of transport. Road transport offers much more on this dimension.

Shipping services are usually also distinguished by a lower service frequency than road transport services. It is quite normal for companies using trucking services, to have daily deliveries and pickups, often even several times a day. This is not the case with shipping services, unless the amount of goods to be transported on one route is so high, that it is rentable to have a service on a daily basis. It can be almost said that the high loading capacity of vessels is a blessing and a curse at the same time on this scale.

Regarding the predictability and delivery security of sea transport, it can be said that there might be instances where the mode is worse than road transport. Maritime routes can be still hindered by dominant winds, currents and general weather patterns, despite the technological improvements for vessels and navigation systems. For the example of

Norway, the North Atlantic (50 to 60 degrees up north) can be seen as such a critical zone. Depending on the season, heavy waves during the winter months can lead to interruptions of sea traffic and cause delays (Rodrigue/Comtois/Slack 2006).

Even though road transport is not classified as the fastest transport mode, it is still seen as a faster option than sea transport. Lead time is perhaps one of the biggest drawbacks for ships, since they are considered as slow by averaging sailing speeds of around 15 knots (28 km/h) and the above-mentioned aspect of time required for transshipment activities, which further increase the total lead time of a transport conducted by vessels (Rodrigue/Comtois/Slack 2006).

4.5.3 Opportunities

Due to a variety of reasons, sea transport can be seen as a viable solution for the transport of fresh farmed salmon from Norway to Europe. The Norwegian salmon farming industry has already a large output of salmon designated for the export to Europe and this volume will further increase over the next couple of decades. Hence, it should not be a problem to reach a high capacity utilization of the Hav Line vessel, when fully operational. This factor might be a problem for other vessel types. Ro-Ro vessels i.e. have higher loading capacities and could be challenging to consolidate the necessary volumes in their case. A further issue are return cargo flows to Norway, since it is also difficult to gather enough freight for return trips.

Lead- or transport time might be an issue, depending on the respective route, but certain destinations should be suited for sea transport regarding the acceptable lead time. All transport operations from Central– and South Norway down to Denmark should not be seen as an issue, as long as there are not too many port calls on the route. The Hav Line vessel as an example, goes directly from the collection points to the delivery point in Denmark. Road transports on these routes have to either take a detour through Sweden or take ferries to reach their destinations in Denmark. Furthermore, road transport from North Norway might not seem as the best transport solution for this particular route and type of good. Despite the fact that road transport is seen as less economical over longer distances, rough winter conditions are another limitation factor. The road conditions during the long winter can be quite bad and lead to frequent interruptions of traffic and hence cause delays and supply disruptions. A further factor that might provide sea transport with an advantage regarding lead time, is so-called super cooling technology. This technology could help to increase the maximal allowed time for transport operations of fresh fish.

Sea transport also offers the opportunity to be a superior export solution for fresh salmon on an environmental- and financial dimension. It was already mentioned that sea transport in its current state cannot be seen as the "perfect" solution to all environmental problems that are associated with transport. There are without question regarding the negative impacts through ships, like the pollution of water through oil spills, the exchange of ballast water or on-sea garbage disposal, etc. Further issues that might be mentioned here are noise- and air pollution (Andersson et al. 2016). Nevertheless, sea transport is considered "cleaner" than road transport and there are ways of reducing the negative impacts of ships. Improvements can be achieved by for instance using bunker oil with lower levels of sulphur oxides or switching to alternative fuel types like LNG, which would lead to a reduction of emissions. Since 2015 for instance, vessels operating in the North Sea SECA are required to use MGO with a low sulphur content of no more than 0.10%. On a global scale this limit will be 0.5% for sulphur contents (IMO 2015).

On a financial perspective, it also known that sea transport is usually the cheapest transport mode. The principle of economies of scale applies to transport costs in a way that freight costs tend to be inversely proportional to the size of the shipment. This means simplified, the larger the loading capacity the cheaper the transport costs per ton (Rodrigue 2017). Due this, it should be possible for sea transport to be cheaper than road transport in the case of salmon exports.

A further opportunity given by sea transport might be a reduction of external effects and the there out resulting socio-economic costs, which is perhaps something that might be more desirable for the society as a whole, than for the cargo owners or transport providers. As already mentioned, external effects or costs arise when the actions of one group have an impact on another group. Further, these impacts are not completely compensated by the first group, which leads to some sort of disadvantages for another group (Bickel/Freidrich 2005, quoted in Miola et al. 2009). In the case of salmon exports through road transport, all arising external costs are not appropriately reflected in transport prices, which leaves some of the damages to the Norwegian taxpayer. Sea transport is not free from external effects, since there are impacts on the environment, but it is considered as a better option than road transport. HGV traffic puts a lot of strain on road infrastructure and aspects like road wearing or traffic congestions through trucks would become insignificant by using sea transport.

4.5.4 Threats

One issue for the actual vessel operator(s) or owner(s) in this case, might be the capital costs that are associated with shipping. The purchase of a vessel requires a significant capital outlay and cannot be compared with the acquisition of a truck. In addition to that, service costs are usually also high. These large investments, can contribute to a situation with severe entry constraints of new sea transport operators. Beside high capital costs for ships, there might also be high investments into infrastructure, in the form of necessary port facilities. Operators of a trucking fleet usually extend or renew their fleet over time, with several purchases at different points in time. This means that initial investments are not as high as for a vessel and more spread out over time (Rodrigue/Comtois/Slack 2006).

Furthermore, it is important for a sea transport solution to provide a predictable service, which is distinguished by a high rate of on-time deliveries. For instance, the goods have to be delivered on time, if a big customer in continental Europe, a large retail chain i.e., plans to sell fresh salmon fillets for a certain period. Delays are not an option in such a scenario, since retailers have to prepare for campaigns like this, i.e. the printing of advertising material. If the delivery is delayed for a couple of days or there are any quality issues with the salmon fillets due to inappropriate transportation, the resulting problems for the retailer can't be undone and the damages are irrevocable in the form of lost sales. These problems will be of course passed on to the responsible members in the supply chain, which are either transport providers or if the transport is done by the salmon breeders, to them and they will finally have to deal with the consequences.

The last consideration here should be that sea transport is not automatically an environmental friendly solution. This is for instance shown by a research conducted through the Norwegian Institute of Transport Economics, which showed that the environmental friendliness of a transport mode has a major reliance on the used technology and its operation. The study examined four different transport options from the same starting point to the same destination, two of them entirely conducted via sea transport, and came up with the result that a vessel using conventional MGO emitted more CO_2, NO_X and SO_X than a transport entirely executed via road transport. However, a vessel using an environmental friendly LNG powered engine had the least emissions in this comparison (Pinchasik/Hovi 2017). A summary of this report is later provided in Chapter 5.3. Vessels impact the environment through several factors and aspects like the used sailing speed, engines or fuel type are decisive when it comes to the question of environmental friendliness.

The following Figure (6) should summarize the mentioned factors in the SWOT analysis and give the reader a clear overview.

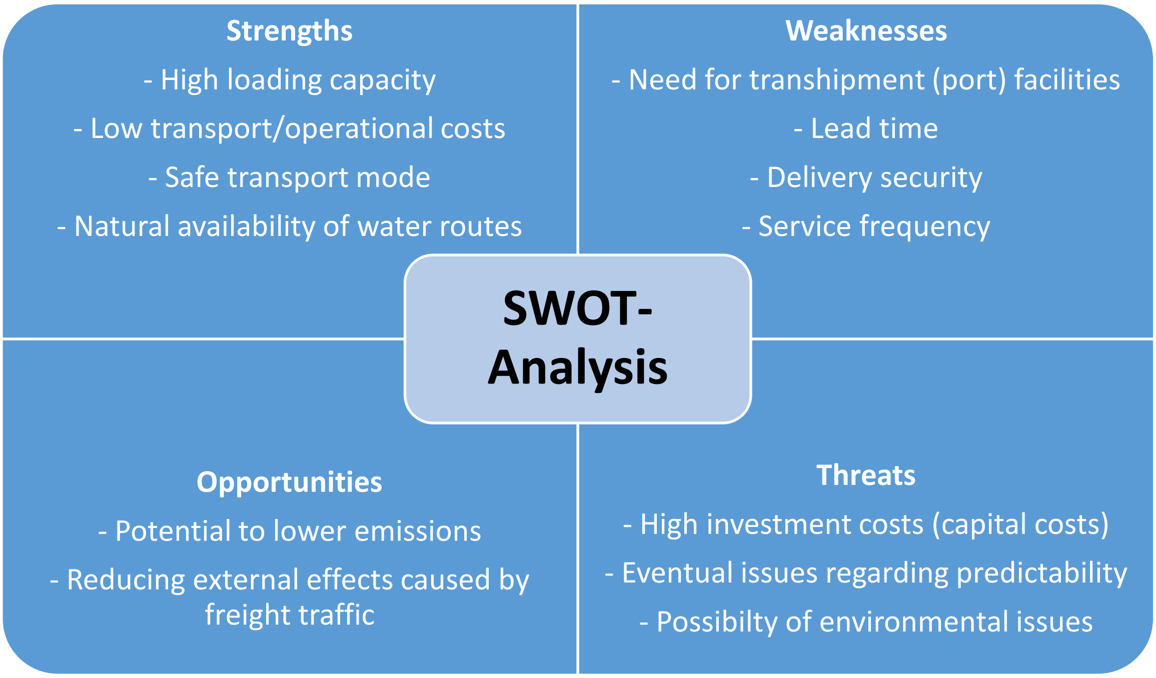


Figure 6: SWOT analysis of sea transport for the transport of fresh farmed salmon.

4.5.5 Summary of the SWOT analysis

In Figure 6, the most important factors from the SWOT analysis of sea transport are presented. Compared to road transport, sea transport has a higher loading capacity. Because of the high loading capacity, one trip with sea transport can i.e. replace a high number of trips with road transport for the same volumes. In addition, the low transport and operational cost, give sea transport an advantage as the cheapest transport mode. The low transport costs come from the limited work force requirement, while the low operational costs are connected to the ability to carry large volumes and have a small energy consumption in proportion to this transported volumes. Another strength is that sea transport has statistically less accidents.

Ssea transport needs facilities, i.e. a port for the movement of the freight from the vessel to land. This decreases the flexibility for sea transport, since there are not ports at all places. This usually leads to situations where door-to-door transport is not possible and sea transport is reliant on road transport to deliver the freight to the end customers in most cases. Compared to other transport modes, sea transport is seen on as the option with the longest lead time.

Including to the fact that sea transport is considered as the cheapest transport mode, it is also seen on as more environmental friendly than i.e. road transport. There are possibilities to reduce emissions from sea transport. This reduction can be done using MGO with low levels of sulphur or switching to alternative fuel types. An opportunity that is more desirable for the society than for cargo owners and transport providers is the possibility of reducing external effects, that are caused by road freight traffic.

One of the biggest threats for sea transport are the high investment costs. The best example on this, are the high capital costs when it comes to purchasing a new ship, the service costs and investments for port facilities. Including to this, it´s worth mentioning that delays for a high volume sea transport can be more severe than for a couple of trucks.

5.0 Previously conducted studies

This chapter was written in order to summarize relevant research that has already been conducted on the topic of fish/seafood transport or export in Norway. The below-mentioned studies cover the issues of reallocating seafood transport flows from road to sea, the carbon footprint and energy usage of Norwegian seafood products and the role of transportation in the Norwegian fishing industry in terms of its value adding or creating function. The following information was partly used to evaluate the current state of alternative transport methods for fresh framed salmon and used to narrow the topic down in order to find existing research gaps. The mentioned papers encompass findings related to environmental science, i.e. emissions and socioeconomic costs, but also business-related factors, like transport costs. One important source for several studies that were used throughout this thesis was TØI.

5.1 Master's degree thesis "Reallocation of seafood freight flows from road to sea"

The thesis was written by the former Molde University College (HiM) students Irina Karlsen and Shulin Huang in 2016 and supervised by professor Arild Hoff and professor Per Engelseth (both HiM). It is focuses on the usage of SSS as an alternative to road transport for the export of farmed fish from Central-Norway to continental Europe (Hirtshals and Zeebrugge). The authors of the thesis cooperated with KNH Kristiansund, Nordmøre port Company and authorities of the Hitra municipality in order to gather information about the pertained shipping network and transport chains. Central research issues of the thesis concern the customer service, cost structure of the planned transport solution and environmental aspects.

The project of applying SSS as a mode of transportation for farmed fish itself, includes seafood producers (Maine Harvest, SalMar, Lerøy), logistics providers (i.e. DB Schenker, Blue Water) and members of "The Coastal Harbor Alliance" (Karlsen/Huang 2016). A case study approach was applied to answer the research questions, whereby interviews, both structured and unstructured, observations, review of information, etc. were used to collect the necessary data for the analysis. The final calculation models were used to derive cost efficiency, lead time and environmental pollutions from the two different transport chains and later also used to compare them with each other (Karlsen/Huang 2016).

Calculation models are based on collected data from the above-mentioned sources and a number of assumptions, made by the authors. Unfortunately, there is no statement regarding assumed load factors of the observed transport modes on their return trips. The initial step was set by computing values for the expected costs while using “pure” road transportation to five different delivery destinations in continental Europe. Calculations for the intermodal transport solution focused on the sea route Hitra-Kristiansund-Risavika-Zeebrugge and necessary post-haulage, conducted via road transport. Results from the calculations show that the intermodal transport solution could be cheaper than regular door-to-door road transport, but requires a certain number of trailers per week in order to be profitable (Karlsen/Huang 2016).

Calculations for the carbon footprint of the transport solutions show that the combined transport chain of sea and road transport has a reduced carbon footprint and the total emissions caused are about two thirds lower than for road transport only. Overall, it can be said that the results from these calculations prove that intermodal transport can be beneficial regarding cost efficiency and environmental protection (Karlsen/Huang 2016).

It was mentioned by the authors that an exact cost structure of the intermodal transport corridor is not presented in the thesis, due to missing information regarding purchasing costs for ships, construction costs for sea ports and possible calculation errors, due to the unavailability of exact data regarding fuel consumption. Further challenges that are not taken into consideration in this thesis included the examination of necessary return cargo flows, possible implantation of new technologies (i.e. autonomous ships, packaging solution, etc.) and the impact of governmental support (Karlsen/Huang 2016).

5.2 transPORT2050 – “Et havnesamarbeid for økt sjøtransport av sjømat mellom Midt-Norge og EU/Kontinentet”

A relevant report for the literature review of this thesis is “transPORT2050”, which was composed by Kysthavnalliansen (Coastal Port Alliance), Trondheim Havn IKS and

Helgeland Havn IKS. The report is built on a survey concerning ports in Central-Norway. It was conducted to map available harbor resources in Central-Norway and give an outline on possible future considerations for the shift from road to sea. The background behind this project and the corresponding survey is based on establishing a new transport route by sea for fresh seafood from the Central-Norwegian region to Europe through Hirtshals (Denmark). Four port companies, from Nordmøre to Helgeland, are currently cooperating to ensure future solutions for freight transport from and to Central-Norway through the "transPORT2050" project (Dekkerhus 2017).

The counties of Møre og Romsdal, Nord-Trøndelag, Sør-Trøndelag and Nordland account for about 50% of production and export of farmed fish in Norway. Out of this volume, about 60% of the farmed fish is exported to customers in Europe. Because of these numbers, there is a strong need for a more comprehensive cooperation between the different modes of transportation, which would be most likely sea and road in this case. "transPORT2050" reinforces regional port, terminal and transport cooperation, in order to handle the arising commodity flows that the seafood exports from this region will account for. It should be mentioned here, that a five-fold production increase is predicted until 2050 (Dekkerhus 2017).

Energy and environmental efficiency, as well as new technologies, such as autonomous ships, are central issues in the project. The goal of "transPORT2050" is to develop and establish sustainably coordinated port services and distribution solutions. This should happen through closer cooperation between stakeholders, whereby ports should be able to exploit their resources more efficiently. Two key locations in this project are the coastal ports of Jøsnøya on Hitra and Kråkøya in Vikna, whereby both are operating terminals that can facilitate trailers to roll on ships, which will be heading to Europe. Together with a strong focus on door-to-door transport, the goal is that maritime transport should be as easy to choose as truck transport (Dekkerhus 2017).

Given the estimated five-fold volume growth in seafood production over the next 30-40 years, it is obvious that it is important to think about how the huge volumes can reach their markets. By moving half of the salmon exports from road to sea transport, it should be possible to achieve a significant reduction of the number of HGVs on the roads. This will have a positive effect on the accident statistics and can give positive environmental impacts (Dekkerhus 2017).

5.3 TØI rapport 1562/2017 – "Miljøregnskap og samfunnsøkonomi for en ny skipsrute fra Kråkøya/Hitra til Hirtshals"

This report was written by TØI and discusses the issue of SSS as an alternative mode of transportation to common road transport for seafood products. It thereby focuses specifically on a possible shipping route from Kråkøya/Rørvik and Hitra (Trøndelag) to Hirtshals (Denmark). (Pinchasik/Hovi 2017) The project is a result of a cooperation between Trondheim Havn IKS and the Coastal Port Alliance, in order to create the mentioned shipping route and reduce road freight traffic (Pinchasik/Hovi 2017).

The report evaluates the existing transport chains, as well as the planned shipping routes and compares them with each other in order to prove, if the new solutions are an improvement of the current state, regarding emissions and caused external costs. It also takes other considerations like the flow of return cargo into consideration, which can be seen as a crucial factor for the sea transport variants. Possible goods for return flows are fruits and vegetables, as well as other goods, i.e. offshore-items, consumer goods, etc. (Pinchasik/Hovi 2017).

Calculations and predictions in the report pertain a period from 2018 – 2050 and examine four different transport variants with regard to their CO_2 emissions and other external costs that are caused by the traffic related to seafood transportation in this particular region. The two already existing evaluated transport chains in the report include unimodal truck transport via Sweden and the Öresund Bridge to the destination in Padborg (Denmark) and an intermodal transport chain that combines truck and ferry, namely between Larvik and Hirtshals. Furthermore, there are also two not yet existing proposed variants, which are mainly sea transport solutions from the corresponding ports in Central Norway to Denmark. Both sea transport chains involve Ro-Ro vessels that transport truck trailers, whereby one alternative uses vessels that is powered by conventional MGO and the other alternative by LNG. Further road transport from Hirtshals to Padborg is conducted via road transport (Pinchasik/Hovi 2017).

Factors that are used for the calculations involve (Pinchasik/Hovi 2017):

- Production volume: 400.000 tons fresh fish from Rørvik/Hitra in 2015, whereby 60% are designated for the European market. Estimated production grow will double until 2020 and have a fivefold increase until 2050.
- Distances obtained from a distance table (Trovik) and marinetraffic.com, as well as Google Maps. Vessel sailing speed is estimated to be 19 knots (possibility for two roundtrips per week).
- Respective engine technologies and fuel consumption.
- Emission factors.
- Capacity utilization.
- Return cargo (more return cargo leads to a positive effect on environmental impact per ton fish).

Results of the study show total CO_2-emission for all scenarios, as well as total distances driven and the caused socio-economic costs by all four transport chains. Some input factors like the usage of a certain vessel type or the predefined number of trips per week under the constraint number of just two available vessels are criticized and there is room for improvement according to the report authors. A further factor that might lead to unreliable findings in the report is the assumption regarding the return flow of cargo (Pinchasik/Hovi 2017).

However, results show that the sea transport route with the LNG powered vessel had the best results regarding CO_2 emissions, even though just slightly better than the combination between truck and ferry. The MGO powered vessel on the other hand, has the worst results of all four alternatives. This can be also traced back to the fact that the vessel has to travel at a relatively high speed, in order to manage two trips per week. Regarding socio-economic costs or external effects, it is calculated that both sea transport routes cause considerable less costs than the transport chains that involve road transport (Pinchasik/Hovi 2017).

5.4 SINTEF Report – "Carbon footprint and energy use of Norwegian seafood products"

The research in this report was conducted by SINTEF. This particular paper was written by researchers from SINTEF's ocean institute for "The Fisheries and Aquaculture Industry Research Fund (FHF)" (SINTEF 2017).

The core topic of this research is to move away from usual studies in the area of environmental concerns that are associated with the production of seafood. Most studies focus on biological impacts through fishing, by-catch and immediate impacts on the ecosystem. However, this one put an emphasis on environmental effects above the ocean surface, which occur due to the usage of modern fishing and fish farming technology (Winther et al. 2009). Not surprisingly, a considerable amount of the caused carbon footprint in the seafood production can be traced back to the necessary transport processes within the value chain of the fishing industry.

The observed value chain for farmed seafood products, i.e. salmon, included four stages, namely the production of feed and smolt, the grow-out phase, slaughtering and further processing, as well as transportation to wholesalers (Winther et al. 2009). For the estimation of the caused carbon footprint during transport, the authors looked at all four modes of transportation (road, rail, sea, air) and available infrastructure. Each model for a transport process includes one component for emissions caused by propulsion/operation related to distance and a further component for the emission caused through cooling processes related to time (Winther et al. 2009).

Data for fuel consumption during road transport was obtained from the logistics department of a large Norwegian salmon producer and verified against other sources like a major European semi-trailer operator and the NTM database. Other data sets include loading volumes and driven distances. Return trips are neglected and it was assumed that the trucks transport other cargo on their return trips; hence, return trips have no impact on the caused emissions through road transport. Two sources of emissions are defined for the cooling process on trucks, the first one occurs due to direct energy consumption from the system and the second one comes from leakage of cooling liquids (Winther et al. 2009).

Three different categories of transport are used for sea transportation, namely bulk freight, Ro-Ro ferries and container transport, depending on the destination of the goods transported and the type (i.e. fresh or frozen). Bulk freight was the only alternative where empty return trips (up to 75% of capacity available) are added due to the actual information. Cooling systems on vessels have a better efficiency than those being used for road transport (Winther et al. 2009).

The results for the impact of transport on the carbon footprint of Norwegian seafood show that this process step takes a considerable share of the total emissions caused. In the case of transportation to the European mainland, transport and necessary packaging are second behind the emissions caused by the feed production for farmed fish, which is the biggest causer of GHG emissions. However, it should also be mentioned that the GHG emissions caused by transport are not just dependent on distances, which have of course a major role, but also on many other variables like truck/vessel size, fuel usage, time, packaging method, utilization and possible refrigeration. According to the authors, so-called "super-cooling" might be one promising way to match customer demand for fresh fish and be more resource-efficient during transportation (Winther et al. 2009). Ellingsen et al. (2009) mentions that it would be promising to aim for change of consumer attitudes towards more frozen fish instead of fresh fish. More frozen fish could increase transport efficiency, reduce waste and decrease the proportion of the worst transport mode regarding emissions, air transport (Ellingsen et al. 2009).

5.5 TØI report 651/2003 about value creation in fish transports

This TØI report focuses on the value creation aspect of transport within the fishing industry. Compared to the above-mentioned papers, it does not put such a strong focus on the environmental issues of fishery. It rather deals with the questions of what value creation is in general and how value can be created by transportation. The paper also concerns further questions, like to which extend is the created value depended on distances to markets, quality of transport and the overall transport offer and how can the value creation be increased. All of the mentioned issues are related to the Norwegian fishing industry and necessary transport processes (Larsen 2003).

The first issue regarding value creation in general is answered by using different theories, like Michael Porter's definition of value or supply chains for instance, inclusive the concept of primary and secondary activities within these chains. The main objective of this concept is to identify competitive advantages of organizations by identifying their key activities. Another theory from Riggs and Robbins (1998) defines value chains as a series of steps, whereby each step adds value and the overall value can be improved through higher quality, lower costs and shorter lead time (Larsen 2003). This means in practice that value can be created by transport, since this process enables that goods or services are accessible at other places than their place of origin or creation. Usually, transport is one of many steps in a value chain that adds a proportion to the final value/price, even though it does not directly transform the characteristics of a product. For the purpose of value creation through transport and an increase of it, it can be said that transport can add more value to products or services if it is cost-efficient, fast and distinguished by a high degree of other services that improve the transport quality or order achievement (Larsen 2003).

After this more general definition of value creation and the connection of this theory to transport, the authors relate this more specifically to the export of Norwegian fresh fish. Therefore, they examined a number of export routes, which had different starting points distributed all over Norway and different destinations around the world. Depending on the location of the final destination, transport modes could vary, and the research included all three types, namely land, sea and air. The mode choice was also dependent on the type of exported fish and its specific requirements regarding lead time. The results of this part show transport costs and lead times to for different routes, as well as the composition of transport costs and their share of the total price (Larsen 2003).

The author also observed the correlation between value creation and transport time, whereby results show that a shorter delivery time could contribute to a higher value of the fish. This is especially a problem for exporters in Northern-Norway, since they have to deal with long distances to export markets and lacking infrastructure. Due to the characteristics of fresh fish, it was also revealed that transport time is a more important criterion for customers than transport costs. The costs usually account for a small proportion of the final price, hence a small to medium increase in transportation costs is often not recognized by end customers. Generally, there is more potential to add value in fish export through transportation for fresh fish products, than for frozen ones.

5.6 Findings in previous conducted studies

The following summary was made in order to give the reader a short and clear overview of what has been said in the aforementioned papers. First, it should be mentioned that a possible shift from road to sea transport for the export of Norwegian seafood is not a completely new topic; it has rather been around for quite some years. This might be due to the fact that seafood in general, or salmon as one specific type, represents an important commodity for the Norwegian economy. Hence, it is important for the sector to build a solid and sustainable basis for the future in order to remain competitive. Further, there are several negative aspects that are associated with road traffic and due to that, this mode of transport cannot be seen as the most suitable choice. However, the actual situation in the sector, with road transport as the prevalent choice as of today, shows that the desirable shift to sea is difficult.

Nevertheless, projects like "transPORT2050" show that there are feasible possibilities for this issue. Papers like the mentioned master's thesis and the two mentioned reports concerning the application of Ro-Ro vessels from Trøndelag (Hitra and Kråkøya) to Denmark as the mode of transportation show that a shift can be accomplished and would make sense, economically as well as environmentally. It is however important, to use "realistic" assumptions in such evaluations. This pertains especially assumed factors for return cargo flows, since selected values for these factors can have a strong impact on results. In some research papers, certain factors are often too optimistic and this leads to scenarios where projects seem viable in theory, but struggle when they are implemented.

The other two reports underline quite well that efficient transportation can be seen as crucial factor for the Norwegian fishing industry. It contributes on one hand to the value of the products, but on the other hand also to negative environmental impacts and external effects that are associated with the export.

The current state of the research on this issue shows, that a shift can be achieved, but there are still open questions that have to be answered. Possible obstacles reach from financial to organizational and environmental aspects. Some of this might be for instance the used vessel types, travel speed, the scheduling of trips, organization of return cargo flows and so on. Anyway, a comprehensive and sustainable solution will require a collaboration of many participating stakeholders.

6.0 Background information about the Hav Line method

In this chapter, the reader will get an overview over the historical development of the salmon farming industry and its importance for Norway. This is followed by an explanation of the export markets for fresh farmed salmon from Norway. Part number three in this chapter covers the general information about Hav Line Gruppen AS, the new vessel and how they are going to operate the salmon export in the start phase. Part four will give the reader an understanding on how the Hav Line method is different from the business-as-usual transport process. After this, the reader is introduced for initiatives for a shift from road transport to sea transport for fresh farmed salmon from Norway.

6.1 Salmon farming industry in Norway

Norway is a fishing nation with long traditions within the aquaculture field. The fishing's position and importance in the Norwegian country was made clear in 1946, when the country got its first Minister for Fisheries and Coastal Affairs (Laksefakta 2016). Due to the geography, Norway is blessed with a long coastline that has been a contributing factor for the importance of the sea. The coastal line facilitates good conditions for fishing and aquaculture activities. "Aquaculture is the farming of aquatic organisms in both coastal and inland areas involving interventions in the rearing process to enhance production. It is probably the fastest growing food-producing sector and now accounts for 50% of the world´s fish that is used for food" (FAO 2018). In 1970, the brothers Ove and Sivert Grøntvedt put out 20.000 salmon smolts in the world´s first salmon farm, located on Hitra. From this point on the salmon industry grew to producing 8.000 tons of salmon in 1980, compared to the 500 tons that were produced ten years earlier. At this time, 70% of the production was located in Hordaland, Møre og Romsdal and Sør-Trøndelag.

In 1990, the volume of salmon production grew to 170.000 tons and the export in 2000 was 343.000 tons. In 2013, the seafood export value in Norway had grown to 61 billion NOK, whereby 42.2 billion NOK came from salmon and trout export. By 2015, Norway has become the largest producer of salmon in the world with respectively 53% of all the Atlantic salmon produced in the world. The value of the exported salmon and trout has by this time increased to 50 billion NOK and salmon is exported to over hundred countries around the world, whereby Europe is by far the biggest and most important market

(Laksefakta 2018). In 2017, the number of exported seafood was on 2.6 million tons to 140 markets all over the world and the value of the exported seafood from Norway had increased to 94.5 billion NOK. The volume increased by 7% from 2016, while the total increase in value of exported seafood was on 3% from the year before (Seafood 2018a).

As the numbers show, the growth and development in the salmon farming industry has been enormous since the start in the 1970´s. “About 70% of the world’s salmon production is farmed. Farming takes place in large nets in sheltered waters such as fjords or bays. Most farmed salmon come from Norway, Chile, Scotland and Canada” (Marine Harvest 2017, p. 36). There aren´t many coastlines that are suitable for salmon farming, because the temperature is a key condition. Marine Harvest (2017) further on explains that the range of temperature optimal for salmon is between 8 and 14°C, but can be between zero and 18-20°C. Including to this, it has to have a certain current to allow a flow of water through the nets. Figure 7 shows the main coastal areas that are adapted for salmon farming in the world. This shows that there are only a few places in the world that possess the right conditions regarding sea temperature and currents that are required.

Figure 7: The main coastal areas adopted for salmon farming (Marine Harvest 2017)

Table 1 shows the top actors in the farmed Atlantic salmon industry in Norway, the United Kingdom, North America and Chile for 2016 (Marine Harvest 2017). The largest producers in Norway are Marine Harvest, Lerøy Seafood, Salmar and Cermaq. In addition to these big companies, the Norwegian market consists of several other smaller producers of farmed salmon.

- Marine Harvest is the largest fish farming company in Norway as of today. The company operates throughout the Norwegian coast from Flekkefjord in Agder to Kvænangen in Troms. In Norway, they cover the entire value chain from feed production to stock fish, roe, food fish, as well as processing and distribution for sale (Marine Harvest 2018b).
- Lerøy Seafood Group is a seafood producer with roots dating back to 1899. The core business of the group is the production of salmon and trout, whitefish catching, further processing, product development, marketing, sales and distribution of seafood (Lerøy Seafood 2018).
- SalMar was founded February 1991 and is today Norway's third largest breeder of Atlantic salmon. The total slaughtered volume for SalMar in 2016 was 129.600 tons of gutted salmon. Since the start, SalMar has gone from being a company with one license for salmon farming in Norway, to an international group with 100 licenses for farming in Norway (SalMar 2018).
- Cermaq Norway AS is one of Norway's largest food producers. The salmon is exported to over 20 countries around the world. Cermaq Norway operates along the coast of Nordland and Finnmark (Cermaq 2018).

	Top 10 - Norway	H.Q.	Top 5 - United Kingdom*	H.Q.	Top 5 - North America*	H.Q.	Top 10 - Chile	H.Q.
1	Marine Harvest	236 000	Marine Harvest	45 000	Cooke Aquaculture	56 000	Salmones Multiexport	50 000
2	Lerøy Seafood	115 700	Scottish Seafarms	28 000	Marine Harvest	43 300	Cermaq**	40 000
3	Salmar	115 600	The Scottish Salmon Co.	24 300	Cermaq**	21 000	Empresas Aquachile	39 000
4	Cermaq**	60 000	Cooke Aquaculture	21 000	Grieg Seafood	10 700	Marine Harvest	36 900
5	Grieg Seafood	40 500	Grieg Seafood	13 500	Northern Harvest	14 500	Pesquera Los Fiordos	36 000
6	Nova Sea	37 100	*		*		Australis Seafood	30 000
7	Nordlaks	35 000					Camanchaca	30 000
8	Sinkaberg-Hansen	29 000					Blumar	28 000
9	Norway Royal Salmon	26 800					Nova Austral	22 000
10	Alsaker Fjordbruk	26 500					Yadrán	20 000
	Top 10	722 200	Top 5	131 800	Top 5	145 500	Top 10	331 900
	Total	1 054 000	Total	141 700	Total	148 100	Total	454 000
	Share of total	69 %	Share of total	93 %	Share of total	98 %	Share of total	73 %

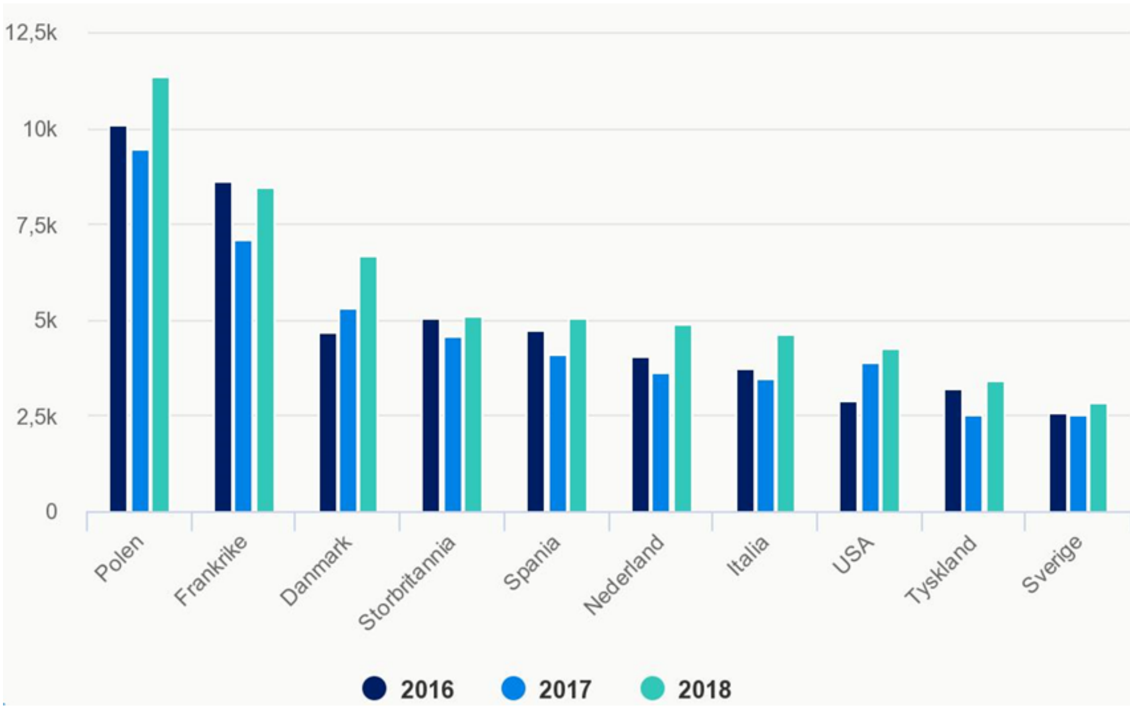
Note: All figures in tonnes GWE for 2016
* UK and North American industry are best described by top 5 producers.
** Cermaq is a fully owned subsidiary of Mitsubishi Corporation

Table 1: Top 10 producers of farmed Atlantic salmon (Marine Harvest 2017)

One of the smaller actors is Hav Line Gruppen AS, which is behind the project of applying sea transport for fresh farmed salmon from Norway to Denmark. The company itself and their project is later described in more detail in Chapter 6.3.

6.2 Export markets for Norwegian farmed salmon

Today, Norway is considered the second largest exporter of seafood. Of all the fish that is caught and processed in Norway, 95% is exported (Seafood 2018b). China is the largest exporter of seafood, but the exports pertain seafood such as squid, frozen cuttlefish, frozen shrimp and prawn, not salmonids. For Norway, the leading species of fish exported in 2015 were salmon and trout (Nag 2017). As mentioned, Norway exported seafood to 140 markets all over the world in 2017. This shows that exported Norwegian seafood is found in almost all parts of the world. The top ten export markets for Norwegian salmon are depicted in Graph 1. When it comes to export markets, it is also important to differentiate between markets for end consumers and markets for further processing of salmon, since freight flows might differ.



Graph 1: Ten largest export markets for Norwegian farmed salmon - amounts in tons (Seafood 2018a).

Poland has been the biggest market for farmed salmon from Norway in the latest years, measured in volume. However, large amounts of the volume are exported to Poland for further processing. Countries like Poland, Denmark and the Netherlands can be looked on as the largest hubs (Seafood 2018b), since they often re-export the farmed salmon further on. As also mentioned, Europe is the most important market for Norway. The United States of America are the only export market within the top ten that is outside of Europe.

Reasons why the European market can be considered as the most important importer of Norwegian farmed salmon is the geographical closeness to Norway.

Norway´s Seafood Council (2018a) pointed out that the export of Norwegian salmon in 2017 increased to the United States and Asia. The export for the market in the United States was 49.000 tons salmon for 4.4 billion NOK in 2017, which contributed to an increase of 25% from 2016. The Asian market imported 169.000 tons of Norwegian salmon for 11.6 billion NOK in 2017, where the biggest importers measured in volume was Japan, Vietnam and South Korea. These numbers contributed to an increase in exported Norwegian salmon volume on 13% from 2016. This shows that the export of Norwegian salmon has increased in several markets over the last year.

6.3 Hav Line Gruppen AS

Haugland Gruppen AS and the Sekkingstad family are the main owners of Hav Line Gruppen AS. Both Haugland Gruppen AS and Sekkingstad have long experience in the salmon farming industry. Sekkingstad was founded in 1923 and is an exporter and processor of salmon. It is Trient AS, the Sekkingstad family's holding company that is listed as a shareholder for Hav Line Gruppen AS. The other shareholder, Haugland Gruppen AS, was established in 2005 and operates among other areas, as a salmon farmer. Hav Line Gruppen AS is owned 50% by Haugland Gruppen and 50% by Trient AS. The goal for Hav Line Gruppen AS is to build, own and operate a vessel that will go directly from farming facilities to Denmark, where further processing will be conducted. All processes of loading, slaughtering, gutting, cooling and transporting will be done on board of the new vessel (Norwegian Coastal Administration 2017).

Figure 8: The new vessel – “Norwegian Gannet” (Wärtsilä 2017).

Chairman of Hav Line Gruppen AS, Jon Hindar, confirmed to Olsen (2017) that the name of the new vessel will be “Norwegian Gannet”. The vessel is planned to be 94 meters long and 18-meter-wide, sailing with a maximum speed of 18 knots. The loading capacity of the vessel per trip is 1.000 tons of slaughtered salmon, which corresponds to 50 truckloads. The vessel is designed by Wärtislä and will have a novel hybrid engine to reduce emissions. It is currently under construction at the Balenciaga shipyard in Spain and is planned to be completed in July 2018. The Norwegian Coastal Administration (2017) states that the boat has a slaughter capacity of 100 tons per hour and the planned number of trips per year is 150. This means that the total amount of fresh salmon transported from the Norwegian West Coast to Hirtshals can be as much as 150.000 tons each year. In comparison, they mention that this can reduce the usage of 7.500 trucks on the Norwegian roads carrying the same amount of freight.

Since the vessel is the first of its kind, it is difficult to know how long it is going to take before the vessel is fully operative with full capacity, depending on how the concept is received in the marked. Hav Line Gruppen AS has set up a plan for how much volume the vessel will take in the first periods after the start in 2018; until 2022. This is separated into four periods (Norwegian Coastal Administration 2017):

1) 01.07.2018 until 30.06.2019: Hav Line Gruppen AS plans to transport 25.010 tons of salmon or trout from Bergen to Hirtshals.
2) 01.07.2019 until 30.06.2020: Hav Line Gruppen AS plans on an increase, so that they will be transporting 30.770 tons of salmon or trout that the company has contracts on.

3) 01.07.2020 until 30.06.2021: Hav Line Gruppen AS will continue to increase its volumes, so that they will be transporting 32.571 tons gutted salmon or trout.
4) 01.07.2021 until 30.06.2022: Hav Line Gruppen AS expects the concept to be fully operative and accepted in the market by this, so that the vessel will transport a minimum of 34.072 tons salmon and trout yearly.

Hav Line Gruppen AS also mentions that if the results for quality and customer satisfaction are reached in the first 12 months, they hope that they will reach the estimated freight volumes earlier than assumed. Conducted calculations regarding the profitability of the project, show that the vessel has to transport at least 32.000 tons per year in order to break-even (Norwegian Coastal Administration 2017).

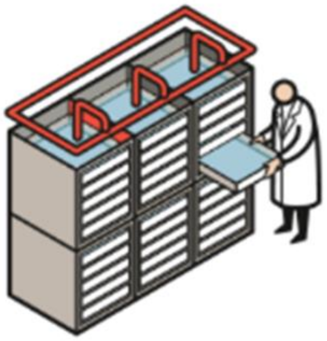
The new vessel will have a new and energy-optimized engine from Wärtsilä, which Enova (2016) has called a pioneering hybrid solution for the seafood industry. The producer of the engine, Wärtsilä (2017), says that "notable environmental gains are made possible by a Wärtsilä hybrid propulsion solution supported by batteries, which results in very low emission levels. This is the world's first processing and transportation vessel for the fish farming industry to utilize this solution" (Wärtsilä 2017). The new vessel will also carry refrigerated tanks with seawater, which will help to maintain the quality of the fresh salmon (Norwegian Coastal Administration 2017).

Including to this, the new vessel will use a downstream wastewater process. The concept of the downstream wastewater process is that all process water has to be filtered, ozonized and chlorinated before it is going to be released. This means that if the processed water isn´t clean, it can´t be released and has to go through the cleaning facility again. This is done continuously until the processed water is clean. To control the cleanliness of the water, tests are taken before it is released to the ocean. There are back-up systems and alarms if there is something wrong with the system, which will help to keep the tests under control and the processed water clean. All the treatment of the water and the emissions of water from the boat will be logged in a computer that isn´t accessible for the crew of the vessel, it can only be read by authorities under supervision (Arnesen 2018).

6.4 Comparison of the business-as-usual value chain and the new solution

The life cycle of a salmon spans from an incubator tank over its time in cages in open water to the point where it is processed and can be sold to the customer. The steps in such a value chain are like in any other value chain connected through a number of distribution processes.

In order to become a ready-for-sales product, salmons need three years. It all starts on land, in an incubator tray with freshwater. This is where the salmon roe is fertilized and lies for hatching for about 60 days. The salmon roe is hatched to small fish with a plum bag that provides food for the first stage. After this step, the young smolts are moved to larger fresh water tanks and lives there for ten to 15 months, until they have grown to 60 to 100 grams. By reaching this size, the smolts are ready to be moved to seawater (Laks 2018).



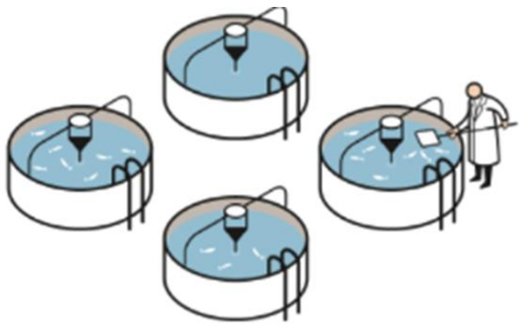


Figure 9: Step one – Salmon roes in incubation tanks (hatching process) and Step two – fresh water phase in on land tanks (Marine Harvest 2018a).

During the moving process to the seawater cages in well boats, the percentage of salt in the water is increased gradually. This helps the smolts to adapt to the seawater. The smolts or later salmons are held in the cages until they have grown to a size between four and six kilos. Careful observations during this process are necessary in order to evaluate if the livestock is healthy. One big threat to salmons is for instance the so-called salmon lice. The growing step can take 14 to 22 months (Laks 2018).

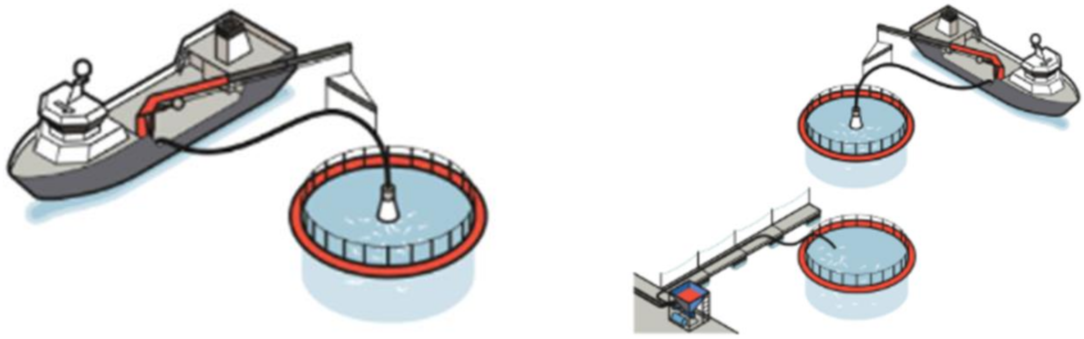


Figure 10: Step three – Moving to seawater and Step four – Growing in seawater with the following well boat transport to land for slaughtering (Marine Harvest 2018a).

After the salmons have reached the right weight, they are transported to the on-land processing facilities, where the slaughtering step takes place. Like for the transport to the cages, well boats are again used in this step. Before the slaughtering process, the fish get numb in order to reduce stress and suffering. At this point, value chains can already differ from each other, depending on where further processing takes place. Some producers conduct further steps like processing and packing in Norway, other producers have outsourced these activities to other countries like Poland i.e. (Laks 2018). After all the processes are done, the salmon is packed with ice and transported to customers all over the world. The fresh salmon is then distributed worldwide through trailers, rail, vessels and air freight, depending on the destination. For a perishable good like salmon, the top priority is always to maintain freshness and quality and to limit transport time (Laks 2018).

Figure 11: Step five – Slaughtering and further processing and Step six – packaging for distribution (Marine Harvest 2018a).

6.4.1 Business-as-usual transport

The new Hav Line and business-as-usual value chains are identical up to the point where the salmon is ready for slaughtering. In the business-as-usual value chain, the salmons are collected at the cages, loaded into a well boat, transported to the slaughterhouse and stored in tanks until it´s time for the salmon to be killed. After the salmon has been pumped into the machine for slaughtering and has been killed, further processing will be realized or the transport to a respective site for the next steps will take place. In the case of the Hav Line method, conventional salmon transport uses mostly trucks to transfer the fresh salmon from the slaughterhouse to Denmark by using the Norwegian road network and various ferry connections (Norwegian Coastal Administration 2017).

Today´s business-as-usual transport is done by combined transport, which includes truck and Ro-Ro ferries. First, the trucks carry the fresh salmon from the slaughterhouses to the various ferry connections that transport the truck from Norway to i.e. Denmark or Germany. (Norwegian Coastal Administration 2017). Hav Line Gruppen AS mentions ferry connections that are used today for the business-as-usual transport (Norwegian Coastal Administration 2017):

- Fjord Line: Bergen – Stavanger – Hirtshals.
- Color Line: Kristiansand – Hirtshals, Larvik – Hirtshals and Oslo – Kiel.
- Nor Lines: Oslo – Hirtshals.

6.4.2 The Hav Line method

The new vessel that can be seen as a floating salmon harvester, can change several processes in the value chain and combine them in more or less one step. With the Hav Line method, the fresh salmon will be transported directly from the cages to Hirtshals. In some ways, the Hav Line method will revolutionize the aquaculture industry (Norwegian Coastal Administration 2017).

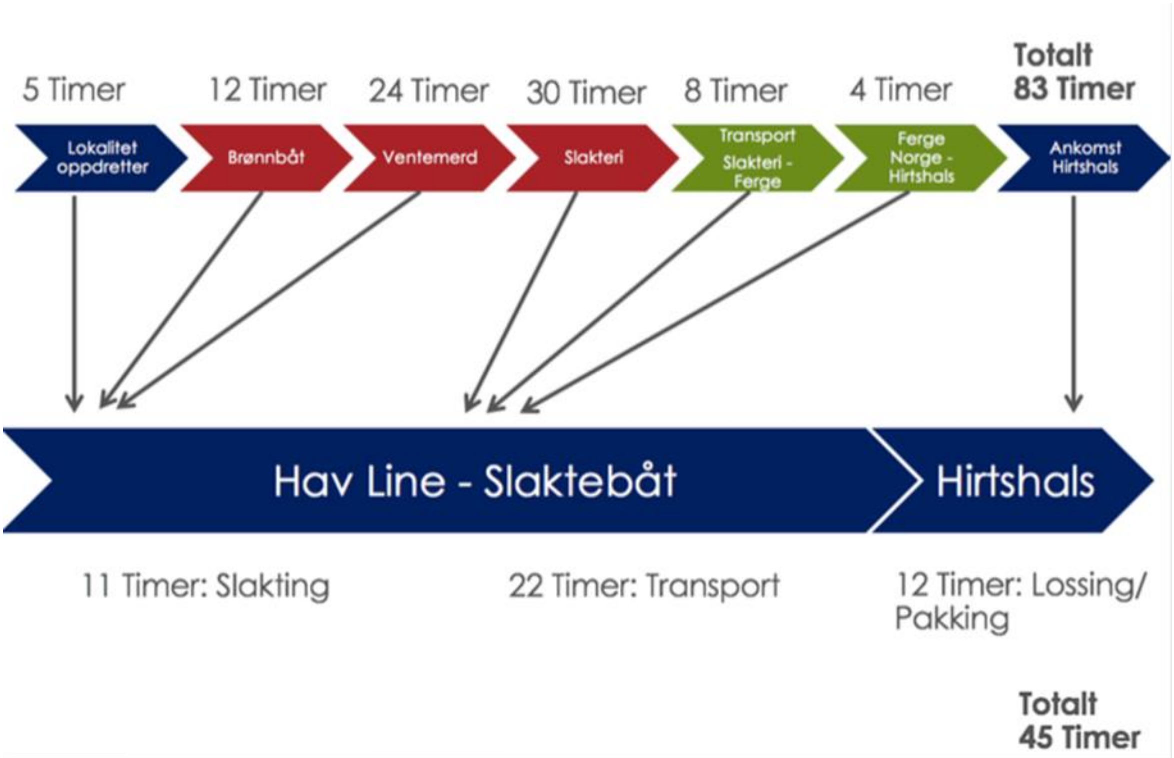


Figure 12: Value chain comparison business-as-usual (above) vs Hav Line method (beyond) (Arnesen 2018).

Usually, the salmon is transported alive to the slaughterhouse in well boats. In the slaughterhouse, the salmon is anaesthetized before it is killed, washed and sorted. After this, the cooling process for the salmon is started. This is done by laying it on ice before it is sent to the different destinations. For the salmon to keep it´s good quality, it is put in boxes with ice inside. The packaging and storage is important, because it can extend the salmons freshness (Laks 2018).

With the new ship, the salmon is picked up at the cages and pumped into the vessel where it is slaughtered and delivered to Hirtshals. In Hirtshals, it is filleted and packed, so that it can be re-exported to other markets. This should create a value for Hav Line Gruppen AS itself in the form of cost savings through cheaper transport and the skipping of the of on land slaughtering facilities. Cost calculations showed that the application of the Hav Line method can lead to a cost reduction of around 30%. These cost savings are achieved by the avoidance of several process steps in the business-as-usual value chain and lower per ton transport costs than normally (Norwegian Coastal Administration 2017).

Furthermore, it should also create value for the Norwegian society as a whole, through reduced environmental impacts by avoiding road transport. As a result, environmental pollution should be reduced, and socioeconomic costs decreased. The Hav Line method will also speed up the process, by reducing delivery time from 83 hours to around 45 hours. This means that salmon will be one to two days faster at the point-of-sale. For the cooling process for the Hav Line method, they will use tanks containing refrigerated seawater, which is a quick and good cooling process that contributes to a longer pre-rigor time for fish. During the travel from Bergen to Hirtshals, the fish will remain in the tanks. The tanks with refrigerated seawater allows the fish's core temperature to be below 0℃ upon arrival at the unloading station. This will give possibilities for further transportation in alternative packaging and reduce the need for ice. This will contribute positively both on cost and environmental (Norwegian Coastal Administration 2017).

As shown in Figure 12 and mentioned previously, the Hav Line method reduces the delivery time from 83 hours to 45 hours in total. Here, it is worth noting that the actual transport will take a significant number of hours more with the Hav Line method than with the business-as-usual transport. The time it will take from the slaughterhouse to Hirtshals in the business-as-usual transport is about 12 hours, while the Hav Line method requires approximately 22 hours. This shows that the actual transport takes more time with the Hav Line method. The Hav Line method speeds up the process during the slaughtering process, which will take around 11 hours. With business-as-usual it takes 71 hours for the well boat to go from the cages to the waiting cages. At the waiting cages, the salmon has to “rest” for 24 hours before it is slaughtered and packed for transport with truck.

Hav Line (2017) mentions that some of the challenges with this new solution will be connected to the cooling of large volume of salmon, lifting of the large volumes from the vessel to the grading and packaging, achieve a good capacity utilization. However, the possibilities it can provide, it has a significant potential in other areas of Norway and other countries (Hindar 2017).

The facilities in Hirtshals can be seen as a strategic placement for the market of fresh Norwegian salmon. In an upstream perspective, this is a central placement for transport of fresh salmon to Europe from both Norway, Iceland and the Faroe Islands. The grading and packaging facility in Hirtshals are under reconstruction and the area will when completed contain a receiving facility, packaging factory, terminal, freezing plant and a processing plant. This has a short distance to Hav Line Gruppen AS´s operational area and the port will have the entire necessary infrastructure that´s needed. In a downstream perspective, Hirtshals is a gateway to the main market of fresh salmon, which is Europe. There are good infrastructure and road connections to Europe and airports. There is also a potential for environmental transport with railway. As Norway, Denmark has a strong culture of fishing industry that has led to a facilitation from the Government (Hindar 2017).

With this method, Hindar (2017) mentions advantages that the customers and farmers can gain. Advantages for the farmer can i.e. be an estimated reduction of loss for the living salmon during the transportation from the waiting cage of 1-3%, less manipulation of the salmon will reduce the escape risk, reduction of risk for biological contamination, improved welfare of the salmon due to less handling and fewer manipulations and it can liberate more capacity. Advantages for the customer can i.e. be longer shelf life due to lower flesh temperature and shorter cycle time, reduced freight cost from less usage of ice and Styrofoam boxes, reduced carbon footprint and reduced road transport of about 7.500 trucks per year at full utilization of the vessel capacity. Including to this, it will be a part of further developing the industry when it comes to environment, fish health, quality, efficiency and cost reductions (Hindar 2017).

6.5 Initiatives for the shift from road to sea transport

When establishing new offers for sea transportation, this process is often connected to high costs when starting up simultaneously with low freight volumes in the early stages. Often these problems regarding costs can be seen on as an obstacle when projects like the Hav Line method are planned and this is why the importance of subsidies is high. Projects that have initiatives to shift from road to sea require therefore often some kind of financial support.

The Norwegian Coastal Administration (2018) mentions some advantages with sea transport compared to the other transport modes. These advantages are that the society gets a gain with a shift of transportation of freight from road to sea, due to reduced environmental impacts. The goals is to achieve a shift of 30% to sea transport for all transports over 400 km.

6.5.1 Subsidies for the Hav Line method

To transfer freight transport from road to sea, different funding schemes have been implemented over the last years, in order to help projects with the mission to accomplish this shift. Incentives and subsidies can be good examples on funding schemes that can be used for this purpose.

In 2017, the Norwegian Government introduced a subsidy which goal is to transfer freight from road transport to sea transport. The Ministry of Transport grants the subsidies, while the Norwegian Coastal Administration administers and manages the funding scheme. In Norway, there were six projects in 2017 that got a subsidy of 93 million NOK in total from this funding scheme. These projects have calculated that they can move 2.7 million tons freight from road transport to the sea during the three years they have the support from the Government (Norwegian Government 2017). In the preliminary project, Hav Line Gruppen AS has received funding from the Norwegian Research Council of 3.250.000 NOK for the period 2014 until 2016 (Norwegian Coastal Administration 2017). One critique that this funding scheme has received is that the subsidy goes to the operator of the ship, not the actual company that changes transport mode for their freight. Hav Line Gruppen AS has as of today contracts with two other companies to carry 15.000 tons for each company, given that the new vessel will work as it´s supposed to (Norwegian Coastal Administration 2017). This means that Hav Line Gruppen AS will receive subsidies for these two companies freight, since they are the operator of the ship.

Hav Line Gruppen AS wishes to promote its environmental profile both as a trademark and to focus on this issue in order to promote innovation in the industry. Enova has contributed support of 6.550.000 for the propulsion solution on the vessel (Norwegian Coastal Administration 2017). One of the reasons to why Enova has chosen to give asubsidy to Hav Line Gruppen AS is the engine that is used for the new ship. (Enova 2016). Further on, Enova (2016) has the opinion that it´s important that the new solution has a potential for transfer the technology forward to other ships, which can result in even more reduction in the greenhouse gas emissions. As mentioned earlier, the producer of the engine, Wärtsilä (2017), says that “notable environmental gains are made possible by a Wärtsilä hybrid propulsion solution supported by batteries, which results in very low emission levels. This is the world’s first processing and transportation vessel for the fish farming industry to utilize this solution”.

6.6 Findings in research about the Hav Line method

Fish has historically been an important resource for Norway and is today considered the second most important export commodity, where today only oil is considered more important. Including to this, it´s important to remember that the salmon industry is expecting a production growth that will double until 2020 and increase by a fivefold until 2050. This shows that the salmon industry, or the fishing industry in general, will be even more important in the future.

Introducing new solutions will always bring both advantages and challenges; this pertains also the new Hav Line method. The new value chain of the Hav Line method will reduce the number of steps that are necessary today, for the same processes. It will lead to a 30% cost reduction and reduce the time-to-market.

To make the new vessel more sustainable, Hav Line Gruppen AS has focused on the environmental aspect when it comes to the design of the vessel and the engine. Especially the engine, which is described as a pioneering hybrid solution for the seafood industry.

Because there is a need to reduce the number of trucks driving through Norway with salmon due to the tearing on the roads, emissions etc., sea transport and transport by railroad is often suggested to relieve the pressure on the increasing transport by truck. To set up a new transport route like it´s done with the Hav Line method, is expensive. Therefore, the Hav Line method has to date got subsidies from Enova and the Norwegian Government for a total of 9.800.000 NOK.

7.0 Evaluation of the Hav Line method

The evaluation of the Hav Line method in this thesis is focused on the environmental performance of this new transport alternative. It is thereby compared against two different business-as-usual transport chains. Both of these business-as-usual transport chains represent intermodal transport solutions that combine road transport and sea transport. The evaluated aspects for all three transport alternatives pertain the caused emissions by each alternative and examine socio-economic costs related to the transport chains. The observed transport chains are all used for the export of fresh farmed salmon from Norway to Europe.

The first part of this chapter explains the different transport alternatives, including routes, used means of transportation and related assumptions. Part two and three display the applied calculation models, input data and assumptions, as well as results for caused emissions and socio-economic costs.

7.1 Transport alternatives

The first observed transport alternative represents the new Hav Line method, which will apply a specialized vessel that combines the slaughtering and transportation of salmon. It is planned that the operation of this vessel will start by the 01.07.2018. The two business-as-usual transport chains include the application of HGVs for road transport in combination with Ro-Ro ferries for the respective sea transport sections of the routes.

7.1.1 Hav Line method – transport route

The planned operational area of the specialized vessel is going to be located on the Norwegian west coast, specifically south of the area of the Stad peninsula (Selje Municipality) (Figure 13). As mentioned in Chapter 6.4, the vessel will go directly to the salmon farms within the operational area in order to collect the living fish. Stunning and slaughtering processes will subsequently follow the loading processes. The activities of collecting, stunning and slaughtering will take 11 hours on average. The actual transport of the slaughtered salmon is separated from the just mentioned process steps and will require 22 hours on average from the operational area to Hirtshals. Single trips can be either shorter or longer, depending on the locations of the selected salmon farms, which can be either within the Southern parts of coastline within the county of Vest-Agder or further up the coastline in the Northern parts of the county Sogn og Fjordane. The vessel will use an average sailing speed of 15 knots and carry 1000 tons of salmon in an ideal scenario with a full utilization of its loading capacity (Norwegian Coastal Administration 2017).

One trip of the vessel to Hirtshals will cover a distance of 330 NM (611 km) on average. Pre- and post-haulage with other transport modes are not needed for this transport alternative, since fish is collected directly from farms and directly shipped to the facilities that are used for further processing after the salmon is slaughtered. However, the vessel used for the Hav Line method is purpose-built and can therefore only transport salmon. Due to this, the vessel cannot transport cargo on the return-trip and the emissions caused during the return leg have to be fully accounted to the respective transport volumes on the transport leg to Hirtshals. Hence, the load factor of the vessel on the return leg is always zero.

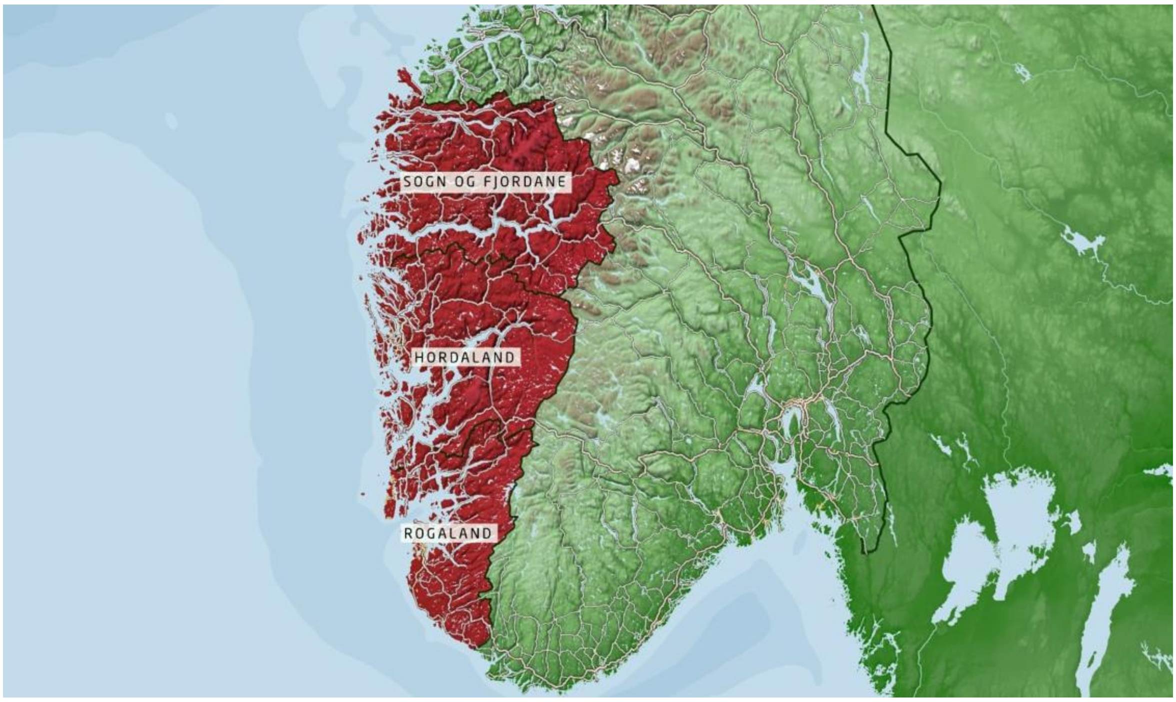


Figure 13: Main operating area for the Hav Line method (Ese 2014).

Important figures for the Hav Line transport route:

- Average one-way shipping distance: **330 NM** (611 km).
- Average time required for a one-way trip: **22 hours**.
- Average sailing speed: **15 knots.**

7.1.2 Intermodal transport alternatives – transport routes

Several existing business-as-usual transport routes are used today in order to transport fresh salmon from the respective area along the Norwegian west coast to Hirtshals. These alternatives are all intermodal transport solutions, by combining road and sea transport. The alternatives include the application of HGVs for road transport from the slaughtering facilities to different ferry links within Norway. The ferry services use Ro-Ro ferries for the sea crossing and go either directly to Hirtshals or to other ports in Denmark or Germany. It is stated in the application from Hav Line Gruppen AS for funding from the Norwegian Coastal Administration (2017) for the reallocation of freight flows from road to sea, that there are no existing "complete" sea or rail transport solutions for these routes at present.

Two intermodal transport routes were selected for the purpose of the comparison between the Hav Line method and business-as-usual transportation. Both routes take Bergen as a starting point, which is in line with named starting point in the above-mentioned application (Norwegian Coastal Administration 2017). As for the vessel used in the Hav Line method, this point can vary from trip to trip, depending on the actual location of the selected slaughtering facilities where the salmon is collected and might be either further up on the Northern parts of the Norwegian West Coast or further down on the southern parts.

The intermodal transport alternative 1 is separated into two sections, the route is shown in Figure 14. Section one is carried out by road transport and leads from Bergen to Larvik over a distance of 429 km, which takes 8 hours on average. The second section of this route is done via sea transport, whereby a Ro-Ro ferry is used to transfer trucks over a ferry link directly to Hirtshals. The distance of this section is 88 NM and takes 3 hours 45 min on average. The final transport leg from the ferry terminal in Hirtshals to the processing facility is neglected due to the short distance.

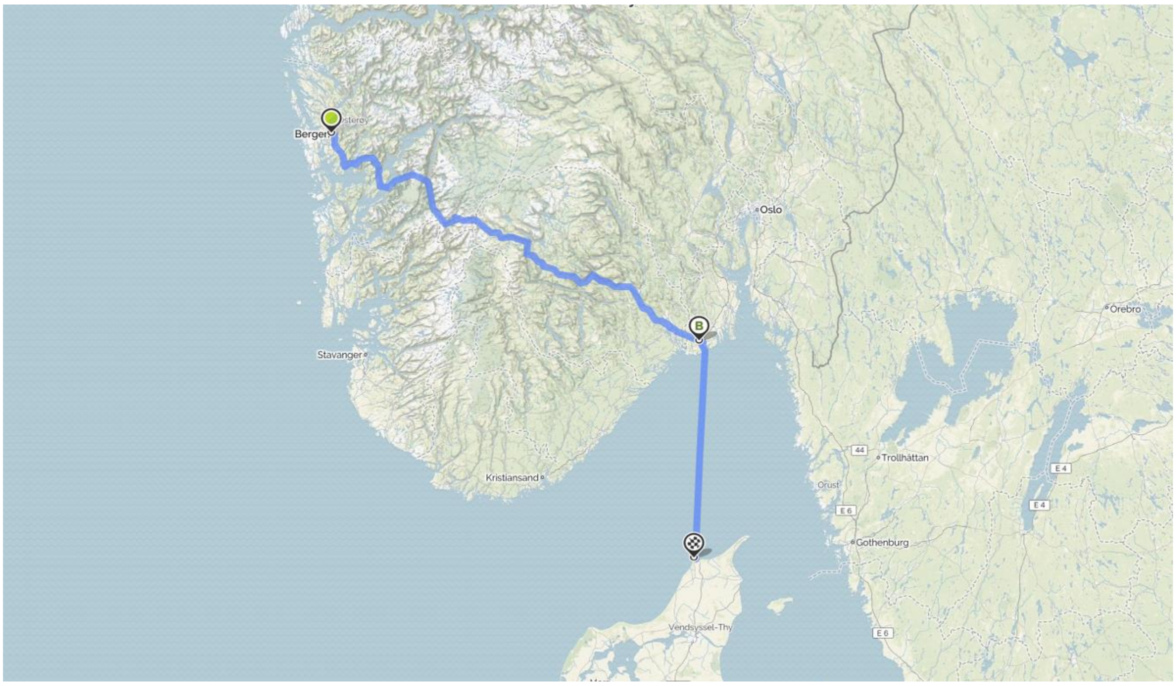


Figure 14: Intermodal transport alternative 1: Bergen – Larvik – Hirtshals (MapQuest 2018).

Important figures for the intermodal transport alternative route 1:

- One-way road transport distance (Bergen – Larvik): **429 km.**
- Average time required for the road transport section: **8 hours.**
- One-way sea transport distance (Larvik – Hirtshals): **88 NM** (163 km).
- Average time required for sea transport section: **3 hours 45 min.**
- Average sailing speed: **23.5 knots.**

Intermodal transport alternative 2 is separated into three sections, the route is shown in Figure 15. Section one covers road transport from Bergen to Oslo over a distance of 463 km, taking 7 hours 30 min on average. Part two is conducted via sea transport from Oslo to Frederikshavn, covering a distance of 156 NM in one direction and taking either 12 hours for the journey from Oslo to Frederikshavn or 9 hours 15 min for the return trip. The Ro-Ro ferry on this link uses a lower sailing speed for the transport leg from Oslo to Frederikshavn with about 13 knots on average. The sailing speed on the return trip averages around 17 knots. After the completion of the sea transport leg, the remaining distance from Frederikshavn to Hitshals is conducted by road transport over a distance of 48 km and takes 50 min on average.

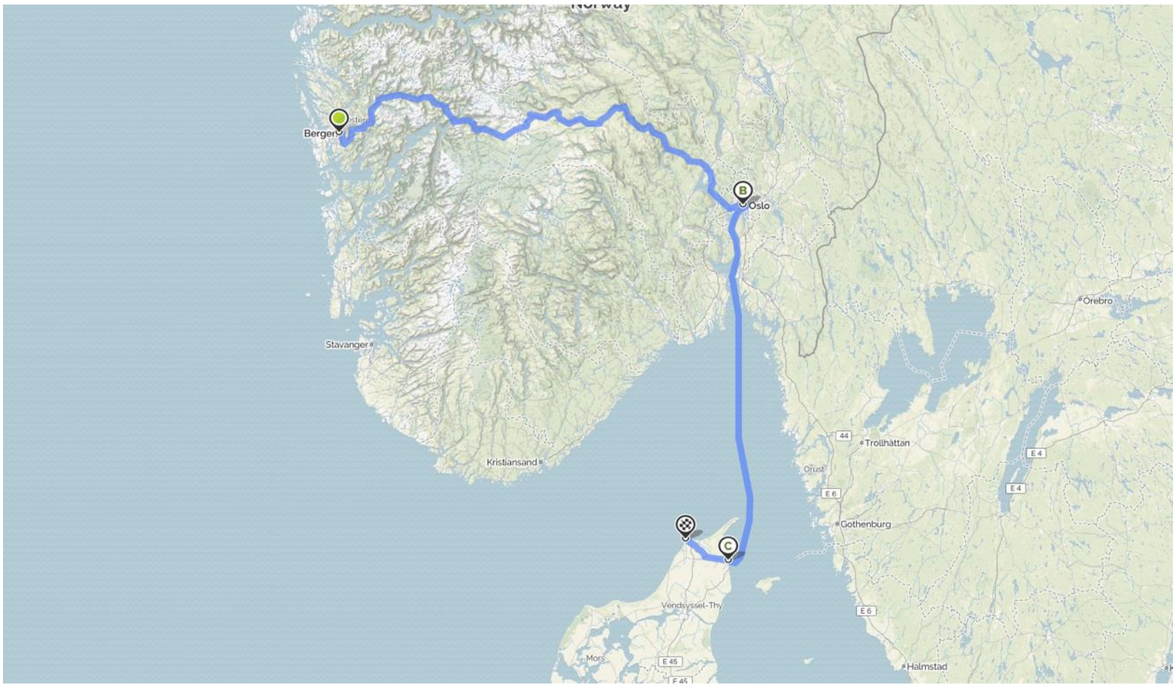


Figure 15: Intermodal transport alternative 2: Bergen – Oslo – Hirtshals (MapQuest 2018).

Important figures for the intermodal transport alternative route 2:

- One-way road transport distance section 1 (Bergen – Oslo): **463 km.**
- Average time required for the road transport section 1: **7 hours 30 min.**
- One-way sea transport distance (Oslo – Frederikshavn): **156 NM (289 km).**
- Average time required for sea transport section (Oslo – Frederikshavn): **12 hours.**
- Average sailing speed (Oslo – Frederikshavn): **13 knots.**
- Average time required for sea transport section (Frederikshavn - Oslo): **9 hours 15 min.**
- Average sailing speed (Frederikshavn - Oslo): **17 knots.**
- One-way road transport distance section 2 (Frederikshavn – Hirtshals): **48 km.**
- Average time required for the road transport section 2 (Frederikshavn – Hirtshals): **50 min.**

7.2 Emission calculations

The first part of the following subchapter explains the key factors and assumptions that were necessary for the applied calculation models. Part two continues with a description of the used calculation models for emission values of each transport alternative. The transport alternatives are compared on the basis of the emitted amounts of CO_2, NO_X, SO_X and PM per kg transported salmon. The third section of this subchapter shows the obtained results from the calculations.

7.2.1 Overview over key factors and necessary assumptions

This section is separated into key factors and assumptions that either pertain the Hav Line method in the first part or the intermodal transport alternatives in the second part.

7.2.1.1 Key factors and assumptions for the Hav Line method

The Hav line method represents a pure sea transport solution. The used key factors were obtained from presentation “Enova Conference 2018”, received from Carl-Erik Arnesen, CEO of Hav Line Gruppen AS. The applied vessel in this case is going to have a main engine with a power of 6.100 kW (MEP) and two auxiliary engines with a combined power of 3.160 kW (AEP). Maximum sailing speed of the vessel is going to be 18 knots, whereby the average sailing speed applied during transport will be 15 knots. The loading capacity of the vessel is 1.000 tons of slaughtered salmon at maximum. Hav Line Gruppen AS estimates that this transport solution can be used to replace 7.500 trucks for the transport of salmon on Norwegian roads per year, if the capacity of the vessel is fully utilized and 150 transport journeys of the vessel are conducted annually. This number corresponds to 50 trucks per vessel trip. In order to compare all transport alternatives, it was also necessary to take return trips of the respective transport solutions into account. The Hav Line vessel is purpose-built and cannot transport any cargo on its return trip to Norway. Therefore, the load factor on the return trip will be always zero.

The following assumptions had to be made, due to a lack of exact data. These assumptions pertain the specific fuel consumption (SFC) of ME and AE on the ship, average workload factors for both of the engine types and the load factor of the vessel on its trip to Hirtshals. The values for the SFCs and workload factors of engines strongly depend on the actual operation of a vessel and the chosen sailing speed. The values used in these calculations were taken from papers that dealt with similar issues and adjusted to this case. Applied values for workload factors of the engines were 80% for the ME and 20% for the AE. The selected value for the SFC of the AE is 215 g/kWh (Hjelle 2011). Wärtsilä, the manufacturer of the used ME on the ship, states that the implemented engine can have a SFC of as low as 165 g/kWh, which is significantly below other engines of the same type available on the market (Wärtsilä 2015). However, as already mentioned, this value can vary in reality from situation to situation and depends on the actual operation of the ship. It was therefore assumed that the SFC of the ME in this case will be 195g/kWh, which is still below the SFC of the other MEs used in the Ro-Ro ferries in the observed intermodal transport solutions (later mentioned). The assumed load factor of the vessel will be 100% on the transport leg to Hirtshals, which represents an ideal scenario for the Hav Line method. With this 100% load factor on the first leg, the average load factor for the vessel will be 50% on a round trip. A sensitivity analysis is later carried out in Chapter 9.0 and observes different scenarios with different load factors, in order to show the impact of this factor on the emitted values per kg salmon transported.

Table 2: Overview over key factors applied for the Hav Line method.

ME power	6100 kW
SFC ME	195 g/kWh
Average ME work-load factor	80%
AE power	3160 kW
SFC AE	215 g/kWh
Average AE work-load factor	20%
Operating speed	15 knots
Load factor (round trip)	50%

7.2.1.2 Key factors and assumptions for the intermodal transport alternatives

7.2.1.2.1 Intermodal transport alternative 1

The intermodal transport alternative 1 consists, as already mentioned of a first transport leg carried out by road transport (Bergen - Larvik) and a subsequent second transport leg carried out by sea transport (Larvik - Hirtshals).

The trucks used on the road transport leg, as for all road transport sections in this evaluation, have an assumed ME power of 350 kW and a SFC of 250 g/kWh. Average engine workload for the road section in this alternative is estimated to be 50%, which is above usually applied values for standard roads. The reason for this is that the trucks have to drive on hilly roads on their way from Bergen to Larvik, which leads to higher engine workload factors than on flat roads. Trucks used in both of the intermodal transport alternatives have a loading capacity of 26 tons. However, 20 tons of the loading capacity are actually used for salmon, while the remaining six tons are used for ice and packaging material which is required during transport. These 20 tons of salmon per truck are in line with the estimations made by Hav Line Gruppen AS. They state that their vessel will reduce the number of trucks on Norwegian roads by 7.500 annually, if the vessel capacity is fully utilized (Arnesen 2018). The load factor of the trucks is assumed to be 100% when they leave Norway and transport salmon to Hirtshals. However, since it is usually difficult to reach a full capacity utilization on the return trip, it is assumed that trucks won't be fully loaded on their return to Norway. The assumed value for the load factor in this scenario is 40%. The combination of these two values leads to overall HGV load factor of 70% on a roundtrip from Bergen to Hirtshals and back. Different load factors are applied in the sensitivity analysis in Chapter 9.0. The mentioned values for HGV engine power, corresponding SFC, engine workload factor and HGV loading factor were also applied for the road transport section in the intermodal transport alternative 2, from Bergen to Oslo.

Table 3: Overview over key factors applied for the road transport sections in Norway.

HGV engine power	350 kW
HGV engine workload factor	50%
SFC HGV engine	250 g/kWh
Loading capacity	26 tons
HGV loading factor	70%

The sea transport leg from Larvik to Hirtshals is carried out via a ferry link operated by Color Line. The vessel used on this link is named "M/S SuperSpeed 2", a Ro-Ro ferry with a maximum operating speed of 27 knots, which is considered as a high-speed vessel and above the usual operating speed of Ro-Ro ferries (Hjelle 2011). The ME applied in this vessel has a power of 38.000 kW and the power of the AE is 12.000 kW. 117 HGVs can be transported on the ferry when the respective decks for trucks are fully utilized (Color Line 2013).

As for the Hav Line method and the road transport leg, it was also necessary to assume several factors on this route section. The SFC of both, ME and AE are assumed to be 215 g/kWh. Average engine workload for the ME are 80% and 20% for the AE, similar to the workload factors applied for the Hav Line method. As for the HGV load factor, it is also necessary to use to use an average load factor for the ferry, since all available lane meters on the vessel won't be completely utilized during every conducted trip. The average value for the lane meter utilization or the ferry load factor is estimated to be 70% in this case. The last factor required for the calculations is the so-called Ro-Pax factor, which is used to allocate energy use and later also emissions to either passengers or passenger cars and HGVs used for freight transport purposes. The assigned value for the Ro-Pax factor depends on the general layout of a ship, more specifically to how many decks are used for passengers and how many are meant for HGVs. In this case, a medium value of 50% was assumed for the ferry connection between Larvik and Hirtshals (Hjelle 2011).

Table 4: Overview over key factors applied for the sea transport leg Larvik – Hirtshals.

ME power	38.000 kW
SFC ME	215 g/kWh
Average ME workload factor	80%
AE power	12.000 kW
SFC AE	215 g/kWh
Average AE workload factor	20%
Lane meter utilization	70%
Maximum capacity for HGVs	117
Ro-Pax factor	50%

7.2.1.2.2 Intermodal transport alternative 2

The intermodal transport alternative 2 includes three transport legs, which are a road transport leg from Bergen to Oslo, sea transport from Oslo to Frederikshavn and a final leg from Frederikshavn to Hirtshals, which is again carried out by road transport.

It was assumed that the trucks on both road transport legs are identical to the trucks applied in the intermodal transport alternative 1. A description of used key factors and assumptions can be found in Chapter 7.2.1.2.1 and Table 3. The only distinction in the applied key factors for the road transport sections is the selected truck engine workload on the transport leg from Frederikshavn to Hirtshals. It was assumed that the workload in this scenario will be lower than for the hillier roads in Norway. The chosen engine workload in Denmark is therefore 40% due to flatter roads. Engine power, SFC, loading capacity and loading factor are the same as in all other road transport scenarios.

However, the sea transport leg on this transport route shows many distinctions compared to the link between Larvik and Hirtshals. The applied vessel on the ferry link Oslo – Frederikshavn is also a Ro-Ro ferry, but the vessel design and operation are differing from the above-mentioned high-speed ferry. The vessel operator in this case is Stena Line and the applied ferry is “Stena Saga”. This vessel has a main engine power of 22.963 kW and auxiliary engines with combined power of around 7200 kW (Stena Line 2015). The major distinction regarding the operation of the “Stena Saga” compared to the “M/S Superspeed 2” is the applied operating speed, which is significantly lower in the case of the first mentioned ferry. An average operating speed of 13 knots is currently applied on the transport leg from Oslo to Frederikshavn, which leads to a much lower engine workload than in the case of the high-speed ferry, averaging around 23.5 knots. The assumed ME workload on a trip from Norway to Denmark is therefore 40%. However, on the return trip from Frederikshavn to Oslo, the ferry is operated at a higher average sailing speed of almost 17 knots. This leads to a higher estimated ME workload on the return trip of 70%. The AE engine workload is assumed to be 20% on both legs and the SFC for ME and AE is 215 g/kWh.

A further distinction between the two ferries had to be made regarding the Ro-Pax factor. The “Stena Saga” uses more decks for passengers and passenger cars than for vehicles meant for freight transport activities. The chosen Ro-pax factor in this case is 35%, which means that 35% of the energy consumption and emission are accounted to the transported HGVs. The total load capacity for HGVs on this ferry is 70 and the lane meter utilization is 70% (Hjelle 2011).

Table 5: Overview over key factors applied for the sea transport leg Oslo – Frederikshavn.

ME power	22.963 kW
SFC ME	215 g/kWh

Average ME workload factor (N – DK)	40%
Average ME workload factor (DK – N)	70%
AE Power	7.200 kW
SFC AE	215 g/kWh
Average AE workload factor	20%
Lane meter utilization	70%
Maximum capacity for HGVs	70
Ro-Pax factor	35%

7.2.2 Applied calculation models and results

This subchapter includes explanations of the formulas that were applied for the calculations of emissions and displays the obtained results.

The different transport alternatives vary from each other on several perspectives, including applied means of transportation, distances travelled, loading capacities, load factors and factors regarding applied engines and related values for SFC and engine workloads. It was therefore necessary to select one value for caused emissions that could take all these factors into account and enable a comparison of the different transport alternatives. The chosen value for this purpose is the emitted amount of a specific pollutant per transported unit of salmon. This can be for instance gram of CO_2 per kilogram transported salmon.

Several steps were necessary in order to calculate such a value. The first step in the applied calculation models pertained the fuel consumption of each transport alternative, which was done by applying the following formulas:

$$FC_{HGV} = EP \times AWL_E \times SFC_E \times T$$

This formula was used for the calculation of the fuel consumption of a truck (FC_{HGV}), which is given by the multiplication of the engine power (EP); average engine workload (AWL_E); specific fuel consumption of the respective engine (SFC_E) and the time under usage (T).

$$FC_{iv} = (MEP \times AWL_{ME} \times SFC_{ME} \times RPF \times T) + (AEP \times AWL_{AE} \times SFC_{AE} \times RPF \times T)$$

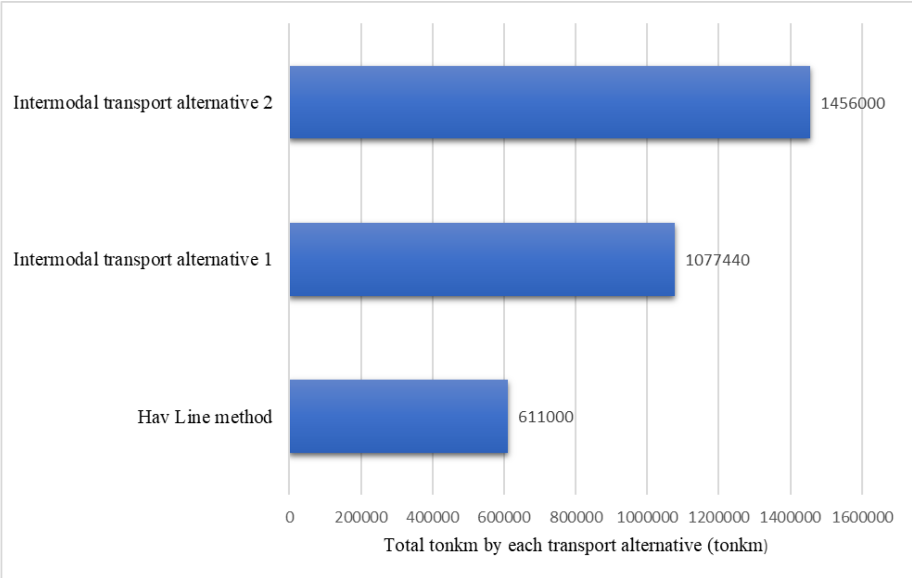
As for the applied formula for the fuel consumption of a truck, this formula was used to calculate the fuel consumption of a specific vessel (FC_{iv}). Due to the operation of a main engine (ME) and auxiliary engine (AE), it is necessary to have two parts in this formula. Part one takes the FC of the ME into account, part two the FC of the AE. FC_{iv} is given by the multiplication of main engine power (MEP); average workload of the main engine (AWL_{ME}); specific fuel consumption of the main engine (SFC_{ME}) and time under usage (T). Additionally, a Ro-Pax factor (RPF) also had to be included, in order to separate the FC_{iv} of a vessel between passengers and vehicles for freight transport activities. The same factors were used in the second part of the formula, with different values related to the AE. The applied formula for the FC of the vessel used in the Hav Line method does not include a Ro-Pax factor, because only cargo (salmon) is transported. Hence, Ro-Pax factors are only necessary for ferries, applied in the intermodal transport alternatives.

Values for the factor T were taken as the total time needed for a round trip, since emissions caused during the return legs had to be included in the calculations. The intermodal transport alternative 2 has differing factors for T on the two sea transport legs (N to DK; DK to N) due to a different operating speed of the ferry on its return trip from Frederikshavn to Oslo.

The next step in the evaluation was the calculation of the total ton-km of each transport alternative. This was done with the following formula:

$$Total\ tonkm_i = CA_i \times LF_i \times Dist_i$$

Total ton-km for a transport alternative i were calculated by multiplying the respective loading capacity (CA_i) of the applied transport mode with the corresponding load factor (LF_i) of this mode and the total traveled distance. Loading capacities as well as load factors varied among the alternatives and are mentioned in the Tables 2 to 5 in Chapter 7.2.1. The factors for the traveled distances ($Dist_i$) for each alternative included the total distance of each round trip for the different solutions. The results for total ton-km for each of the three transport alternatives are shown in Graph 2 and are based on the key factors from Chapters 7.1 and 7.2.1. The numbers are based on the transportation of 1.000 tons of salmon by each transport alternative, which corresponds to a full load of the vessel applied in the Hav Line method.



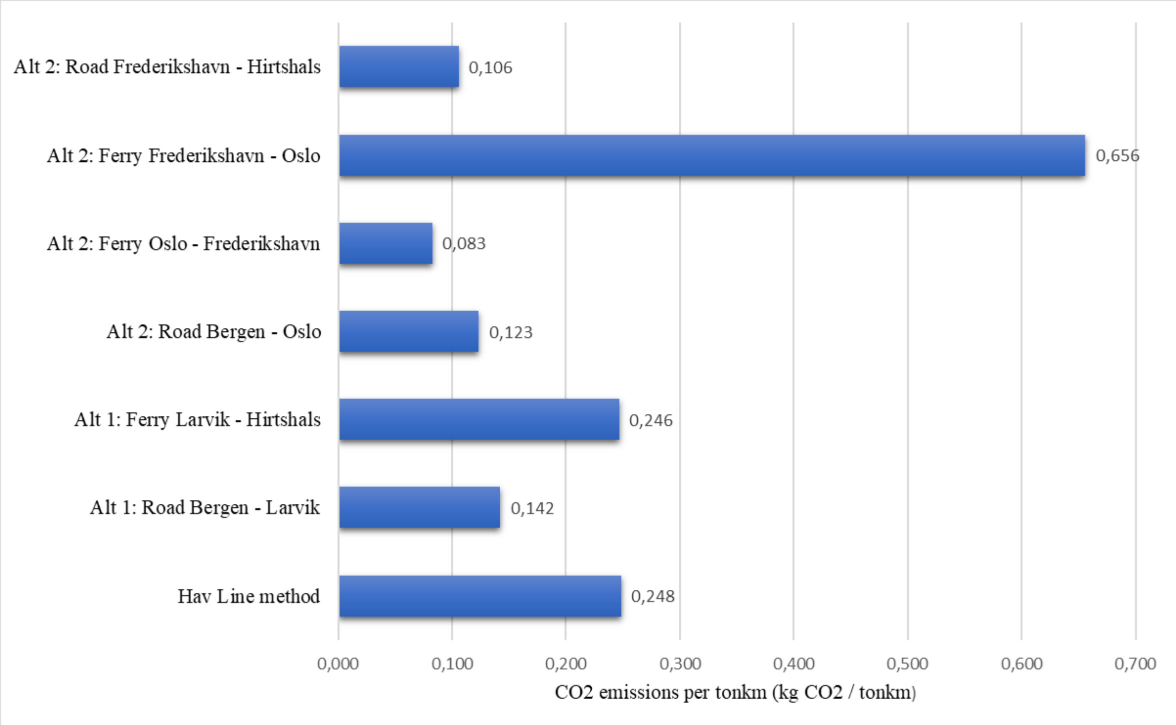
Graph 2: Total ton-km by each transport alternative (ton-km).

Graph 2 displays that the intermodal transport alternative 2 has the highest value for total ton-km. The reason for this is that the distances driven by trucks (Bergen – Oslo; Frederikshavn – Hirtshals; inclusive return legs) and on the ferry link (Oslo – Frederikshavn; inclusive return leg) are longer than for intermodal alternative 1.

All results depicted in this chapter show an “ideal” scenario for the Hav Line method, with a full capacity utilization. Due to fact that the Hav Line vessel is capable of transporting a maximum of 1.000 tons of salmon, 50 trucks are required to transport the same amount to Hirtshals. The number of total ton-km traveled by each transport mode has a strong impact on the emitted amount of kg of CO_2 per ton-km for each transport mode. Results for the lastly mentioned value are shown in Graph 3.

The final values in Graph 3 were obtained by dividing the fuel consumption of a specific transport mode during a roundtrip with the total amount of ton-km traveled on such a journey. Furthermore, this value was multiplied by a CO_2 emission factor for marine gas oil and diesel. The CO_2 emission factor for MGO/diesel was obtained from Statistics Norway and is estimated to be 3.17 kg of emitted CO_2 per one kg of combusted

MGO/diesel (SSB). The only case where the round trip was split into two separate legs is the ferry link in the intermodal transport alternative 2. This separation was necessary due to different operating speeds of the ferry from Oslo to Frederikshavn and on the return from Frederikshavn to Oslo.



Graph 3: CO_2 emissions per ton-km (kg CO_2/ton-km).

The values shown in Graph 3 were used in the calculations for the final results of emitted CO_2 per kg transported salmon by each transport alternative (Graph 4). The numbers above show average values for kg of CO_2 emitted per ton-km traveled by each transport mode. Results are based on the key factors from Chapters 7.1 and 7.2.1. Some of these key factors have a strong impact on the values displayed in Graph 3. An example here for might be the ferry link Oslo – Frederikshavn (N – DK). The average value of emitted kg of CO_2 per ton-km from N to DK is the lowest value for all shown transport modes/legs. On the other side, the ferry link Frederikshavn – Oslo (DK – N) has the highest value for the average amount of kg of CO_2 emitted per ton-km traveled.

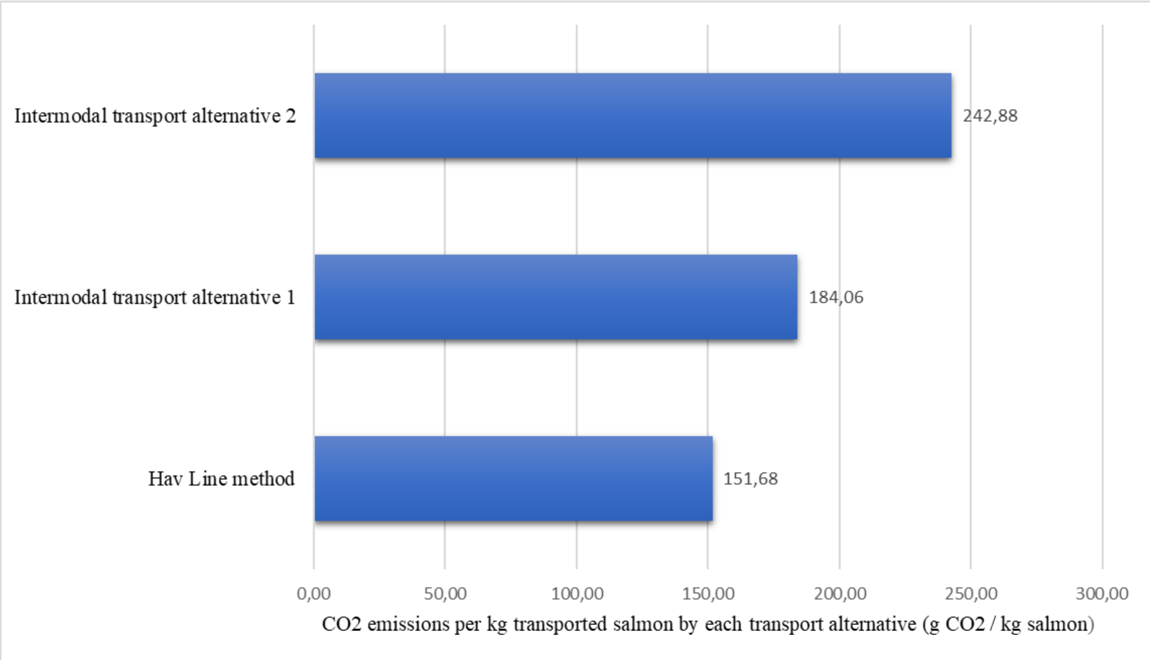
The significant difference between these two values can be explained by the application of different operating speeds of the ferry on this link and different load factors for transported trucks on the ferry. The higher vessel operating speed on the trip from DK to N leads to a higher fuel consumption than on the other way around. In addition to this, it was also assumed that the load factor of trucks is only 40% on their return trip to Norway. This factor of 40% was multiplied with the lane meter utilization of the ferry of 70%. Due to this, the overall loading capacity utilization of the Ro-Ro ferry on this transport leg (DK – N) is just as low as 28%, an issue referred to as “the double load factor problem of Ro-Ro shipping” (Hjelle 2011). High fuel consumption due to a fast vessel operating speed and a low overall capacity utilization of the ferry on the link DK – N, lead to a high value for kg of CO_2 emitted per ton-km travelled. The low value for the link N – DK in the intermodal transport alternative 2 can be explained by the same factors, with the difference that the applied key factors are more “in favor” of this transport leg. Low vessel operating speed and a higher assumed loading capacity utilization of the trucks, lead to a much lower average value for kg of CO_2 emitted per ton-km travelled.

However, the values for kg of CO_2 emitted per ton-km travelled (Graph 3), should not be used to compare the transport alternatives with each other in the context of this evaluation. This is due to the fact that the usage of these values might give a wrong picture of the total amount of CO_2 emitted by each alternative. If only the values from Graph 3 would be used for the comparison, one might assume for instance that the presented Ro-Ro ferry link from Olso to Frederikshavn in the intermodal transport alternative 2 is the most environmental friendly solution regarding CO_2 emission. However, this would be a wrong conclusion, since the presented value for the link is only applicable for this specific scenario, based on the chosen input factors. The input factors in this specific scenario are “in favor” of the transport mode on this specific transport leg (N – DK). It is therefore recommend to use a value that displays the total emissions of CO_2 per kg of transported salmon by each of the three observed transport chains and not just values from certain sections of these transport chains.

Such values were obtained in the next step of this evaluation and are depicted in Graph 4. In order to obtain the total amount of CO_2 emitted by each transport chain, values from Graph 3 had to be multiplied with the total amount of ton-km traveled by each transport alternative for the transport of 1.000 tons of salmon. The total amount of emitted CO_2 for each transport solution are as follows:

- Hav line Method: **151.681,7 kg CO_2**.
- Intermodal transport alternative 1: **184.062,4 kg CO_2**.

- Intermodal transport alternative 2: **242.881,5 kg CO_2**.



Graph 4: CO2 emissions per kg transported salmon by each transport alternative (g CO2/kg salmon).

The final values of emitted grams of CO_2 per kg transported salmon for each transport alternative are shown in Graph 4 which are based on the described calculation models and the mentioned key factors in Chapters 7.1 and 7.2.1. It can be seen that the Hav Line method is the alternative with lowest CO_2 emission, emitting around 21% less CO_2 than intermodal transport alternative 1 and around 60% less than intermodal transport alternative 2. The good result of the Hav Line method can be explained due to the lowest number of ton-km traveled by each of the three transport chains. The second explanation is due to the application of a main engine that is more efficient than the main engines implemented on the Ro-Ro ferries in this evaluation. The bad result of alternative 2 compared to alternative 1, can be traced back to the significant longer time used for the ferry link Oslo – Frederikshavn and the high number for total ton-km traveled (Graph 2).

The evaluation of caused emissions by each transport alternative were further extended to emission values for NO_X, SO_X and particle matter (PM). Land based transport modes, especially road transport vehicles, have strict limits for allowed emissions in the EEA and are therefore often more competitive when it comes to the emissions of the above mentioned pollutants. Euro V and VI trucks for instance, have relatively low particle and

NO_X emissions and are therefore often better in this regard than any other transport mode (Hjelle / Fridell 2012).

Emission factors for the mentioned pollutants were obtained from EPA (2009) for vessels using MGO with a low Sulphur content of 0.1% (MGO-LS). It was assumed that MGO-LS is the used fuel type for all concerned vessels in this evaluation, since all vessels are operated in the North Sea SECA. Values for emission factors are shown in Table 6. Furthermore, it was also assumed that vessels do not use scrubber devices for cleaning processes of emitted gas streams, since no exact information about the eventual application of such devices could be obtained. Emission values for NO_X, SO_X and PM are therefore related to the obtained factors from EPA (2009). The emission factors for Euro V and VI trucks in Table 6 correspond to the current EU-legislation for emission limits of heavy-duty vehicles.

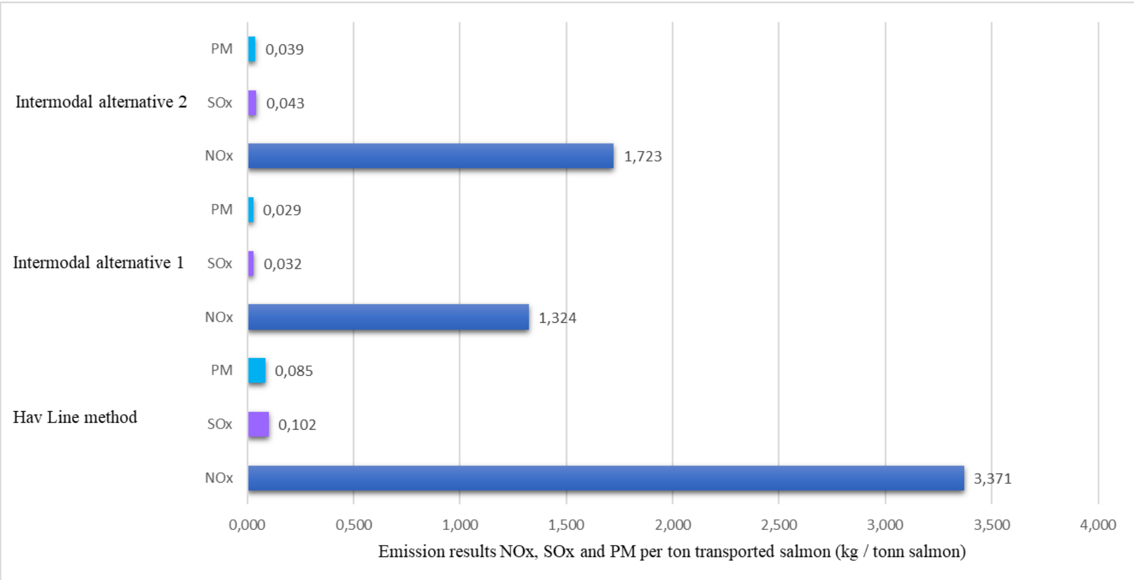
Table 6: Emission factors for different fuel types and transport modes.

Fuel type	NO_X (g/kWh)	SO_X (g/kWh)	PM (g/kWh)
MGO-LS	13.9	0.42	0.35
Diesel (Euro V)	2	-	0.02
Diesel (Euro VI)	0.4	-	0.01

SO_X emissions caused by trucks are neglected in this evaluation. This decision is based on the fact, that SO_X or more specifically SO_2 emissions, are mostly caused by sea transport within the transport sector. In Norway, 19% of the total SO_2 emissions were caused by domestic shipping and fishing in 2007. In comparison to that, less than 3% of the total national SO_2 emissions were caused by other transport modes in the same year (SSB 2008). Due to this, both intermodal transport alternatives only include the SO_X emissions caused by their respective sea transport sections.

In order to calculate the respective values for emissions of the mentioned pollutants, it was necessary to multiply the energy consumption of each transport chain with the respective emission factors. This method was chosen because the obtained emission factors are given in g/kWh and not grams of a specific pollutant per liter combusted MGO-LS/Diesel. The energy consumption of a transport mode is calculated by multiplying the engine power (EP) with average engine workload (AWL) and the time under usage (T). Energy consumption of the Ro-Ro ferries in the intermodal transport alternatives 1 and 2 included additionally to the mentioned factors also Ro-Pax factors, in order to separate the total energy consumption between passengers and vehicles for freight transport purposes. The formula for the energy consumption of all applied vessels consisted furthermore again of two parts. Part one for the energy consumption of the ME and part two for the AE. Input factors for these calculations are again taken from the key factors in Chapters 7.1 and 7.2.1.

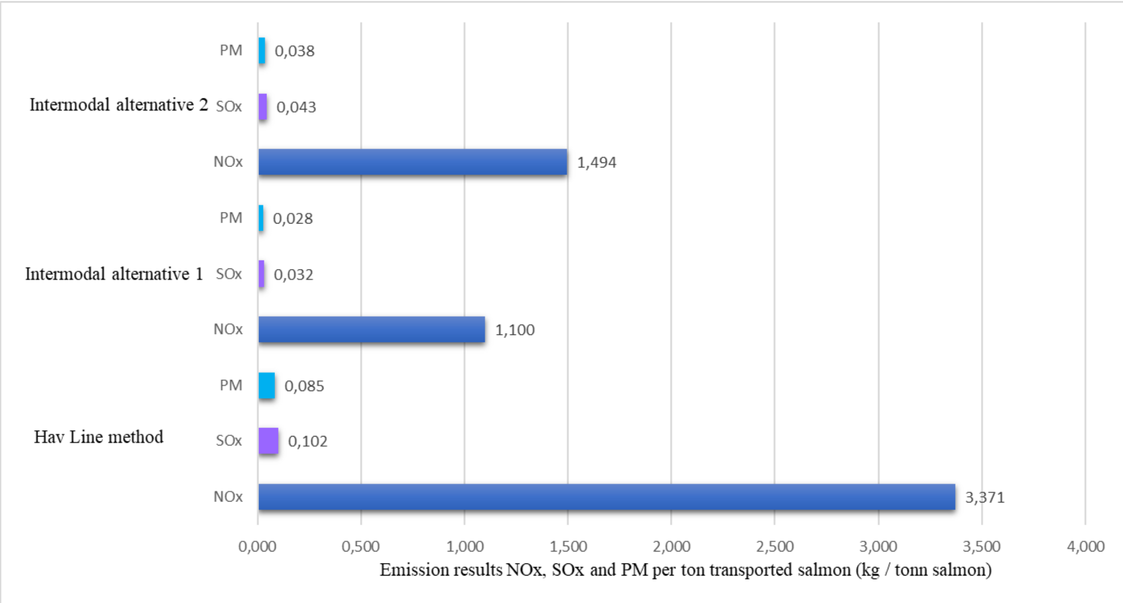
The first observed situation was made for a scenario where all road transport sections in the intermodal transport alternatives apply Euro V trucks. Results for roundtrips are shown in Graph 5. The situation is again related to scenario where 1.000 tons of salmon are transported with each transport alternative.



Graph 5: Emission results NO_X, SO_X and PM per ton transported salmon for Euro V trucks (kg/ton salmon).

Graph 5 depicts the emission values for kg of NO_X, SO_X and PM per ton transported salmon for each transport alternative. As expected, the Hav Line method shows the highest numbers for all three pollutants, due the fact that the entire transport on this alternative is conducted via sea transport. The impact of higher emission factors for sea transport respectively MGO-LS compared to the relatively low factors for road transport (Table 6) can be clearly seen in these results.

The same kind of calculations were also done for a situation where the intermodal transport alternatives apply Euro VI trucks, which have even lower emission factors than the above used Euro V trucks. Results are shown in Graph 6.



Graph 6: Emission results NO_X, SO_X and PM per ton transported salmon for Euro VI trucks (kg/ton salmon).

As it can be seen here (Graph 6), emission values for the two intermodal transport alternatives are lower than in Graph 5. The considerable reduction for NO_X emissions per ton transported salmon can be explained by the applied factor for the NO_X emission limits for Euro VI trucks. The reduction for PM is rather small, due the fact that the difference between the corresponding emission factors for Euro V and VI trucks is not that significant (Table 6).

7.3 Estimations of socio-economic costs

The first part of the following subchapter explains the key factors and assumptions that were necessary for the applied calculation models for the caused socio-economic costs. Socio economic costs were only calculated for the road transport sections of the two intermodal transport alternatives. Part two continues with a description of the used calculation models for the respective transport routes. The two road transport sections of the intermodal alternatives in Norway are evaluated on the basis of average socio-economic costs caused by local air pollution, noise, road congestion, accidents and road wearing. It should be mentioned that the applied calculations use average values from the TØI publication “Marginal external costs of road transport with corrected accident costs” (Thune-Larsen et al. 2014) for the estimations of the caused socio-economic costs. The calculations are therefore rather “rough” estimates.

The socio-economic costs of GHG emissions were not included in the calculations. This is due to the fact, that the socio-economic costs of GHG emissions are difficult to estimate and there is no scientific consensus on the impact of all different types of GHG on the environment and human health. An example here for might be CO_2 emissions and their relation to global warming. A large number of studies agrees upon the fact that CO_2 emissions are contributing to global warming, but have different conclusions regarding the extent of this contribution. It is also challenging to estimate the impact of emissions on human heath, due to difficulties for the determination of the costs of the harm of human health.

The reason why the caused socio-economic costs of the Hav Line method were not included in this part of the evaluation is that many of the aspects that are related to the external effects of sea transport are not applicable for the Hav Line method. The Hav Line method will have, when in operation, no port calls in Norway. Therefore, related external effects of port operations like noise or local air pollution are basically not existent. The impact of GHG emissions is omitted due to the aforementioned reasons. Furthermore, it is known that the vessel is going to apply a filtering system for wastewater, which will reduce further external effects that are related to sea transport, such as disposal of polluted water on sea.

7.3.1 Overview over key factors and necessary assumptions

The key factors for the evaluation of socio-economic costs were obtained from the TØI report “Marginal external costs of road traffic with corrected accident costs” (Thune-Larsen et al. 2014). The observed categories for external effects are shown in the Table 7 to Table 11. The pertained routes go from Bergen to Larvik and Bergen to Oslo. These routes were separated into a number of sections depending on the number of inhabitants in each respective section. This separation was necessary in order to select the correct values for each external effect category. The cost of a category can depend on how many people are influenced. Local air pollution is i.e. more expensive in large urban areas than rural areas. For road wearing on the other hand, it is estimated that accruing costs are the same on all roads in Norway.

The areas are separated into rural areas (>15.000), medium urban areas (15.000-100.000) and large urban areas (>100.000).

The data from Thune-Larsen et al. (2014) provides an overview over the external effect categories of local air pollution, noise pollution, road congestion, accidents and road wearing. The values for NOK shown in this report are from 2012. They were therefore adjusted to the NOK value from 2017 with a price calculator provided by Norges Bank. (Norges Bank 2014) This was done so that the values in the calculations for the socio-economic cost correspond more to the today’s value of NOK. These data was used for both routes.

Table 7: Marginal external costs of local air pollution (NOK/km).

Local air pollution	**NOK/km**
Rural area	0,179
Medium urban area	0,997
Large urban area	4,502
Whole country	0,804

Thune-Larsen et al. (2014) state that local air pollution from road transport is connected to the emissions of environmentally harmful substances from trucks like i.e. particles and nitrogen oxides. Table 7 depicts different values for the costs related to local air pollution depending on the population of an area. Naturally, the NOK/km increases when a truck goes through more populated areas.

Table 8: Marginal external noise pollution costs (NOK/km).

Noise pollution	**NOK/km**
Medium urban area	0,123
Large urban area	0,146
Whole country	0,034

Noise pollution depends on the used vehicle type, but trucks are usually louder that i.e. normal cars. Including to this, different types of engines can be a reason, why some vehicles are louder than others are. Noise pollution is an increasing problem because of an increase in transport operations, population increase and urbanization. Noise pollution can cause satisfactions problems of affected people, health damages and sleep disorders (Thune-Larsen et al. 2014). In Table 8, the marginal external noise costs are listed in NOK/km. The large urban areas are more exposed than smaller areas.

Table 9: Marginal external accident costs (NOK/km).

Accidents	NOK/km
Rural area	0,930
Urban area	2,934
Average	1,445
Whole country	1,445

Table 9 offers a rough estimation of the marginal external accidents costs, because it is difficult to set exact values at how much damage is caused when humans are involved. Another difficulty for the estimations of costs related to accidents, is the degree of injuries from humans and damages of involved vehicles, infrastructure, etc. which can vary by large numbers from situation to situation. (Thune-Larsen et al. 2014)

Table 10: Marginal external road congestion costs (NOK/km).

Congestion	NOK/km
Large urban area	11,995
Whole country	0,123

Road congestion describes a slow flow of traffic or situations where traffic has stopped completely. This is more likely to happen in large urban areas or on main roads throughout the country during i.e. vacations. It is more likely to spend more time for journey when there are more vehicles on the road (Thune-Larsen et al. 2014). Thune-Larsen (2014) has also added vehicle operating costs, inconvenience costs, increased fuel costs and unreliability for the data for marginal external road congestion costs. Table 10 shows that large urban areas are more affected by congestions than other places in the country.

Table 11: Marginal external road wearing costs (NOK/km).

Road wearing	**NOK/km**
All roads	0,856
Whole country	0,856

Thune-Larsen et al. (2014) mentions that the infrastructure of the roads is affected by how "old" the roads are, the climate and how much traffic is driving on that pertained roads. On Norwegian roads, the use of winter tires with studs are necessary in long periods of the year. This is one of the factors that contributes to road wearing; another factor is the weight of the vehicle used. Road wearing does not differ depending on where traffic is happening in the country, the effects are the same everywhere, as seen in Table 11.

As mentioned in previous chapters, assumptions made by Hav Line Gruppen AS states that their vessel will reduce the number of trucks on Norwegian roads by 7.500 annually if the vessel capacity is fully utilized (Arnesen 2018). This number is used as a reference in the calculations of the socio-economic costs for both routes, so that the reduction socio-economic costs can be estimated.

7.3.2 Applied calculation models and results

In the following subchapters show the calculations of socio-economic costs for the two routes in the intermodal transport alternatives (Bergen – Larvik and Bergen – Oslo). The calculations are based on the factors for local air pollution, noise pollution, accidents, road congestion and road wearing.

7.3.2.1 Bergen – Larvik

Table 12 shows the chosen route from Bergen to Larvik, which is the first leg in the intermodal transport alternative 1 mentioned in Chapter 7.1.2. After the arrival in Larvik, the transport for this route is carried out by the Color Line-ferry "M/S SuperSpeed 2" to Hirtshals. Further, Table 12 shows the values for km that were used for the calculations for the socio-economic costs caused on this route. The distances for the different sections in the route were multiplied with corresponding value from each socio-economic cost category (Tables 7-11). This gives the total value of local air pollution, noise pollution, accidents, congestions and road wearing for the respective areas. Distances in Table 12 were taken from Google Maps.

Table 12: Distances Bergen-Larvik.

Distance (Bergen – Larvik)	
Bergen – Åsane (large UA)	15 km
Åsane – Trengereid (medium UA)	23,7 km
Trengereid – Eikedalen (rural A)	25,2 km
Eikedalen – Tørvikbygd (rural A)	31,3 km
Jondal – Odda (rural A)	39,1 km
Odda – Åmot (Vinje) (rural A)	121 km
Åmot (Vinje) – Ulefoss (rural A)	115 km
Ulefoss – Porsgrunn (rural A)	26,5 km
Porsgrunn – Eidanger (medium UA)	11,9 km
Eidanger – Larvik (rural A)	19,6 km
Larvik – Larvik (medium UA)	4,3 km
SUM	**432,6 km**

The results for the single categories of socio-economic costs and their sum on this route are as follows (rounded values):

- Local air pollution: **175 NOK**.
- Noise pollution: **20 NOK**.
- Accidents: **512 NOK**.
- Congestions: **231 NOK**.
- Road wearing: **370 NOK**.
- Total: **1.309 NOK**.

The total value means that one truck journey from Bergen to Larvik causes socio-economic costs of 1.309 NOK, without the consideration of GHG emissions. This total value can be multiplied with the reference number from an ideal scenario for the Hav Line method, where the reduced number of trucks on Norwegian roads is estimated to be 7.500. In a case, where all of these 7.500 trucks would take the route from Bergen to Larvik, the resulting costs would be 9.814 million NOK.

In another scenario where the Hav Line method only transports 60% of the possible transport volume, the number of reduced trucks would be 4.500. The thereout resulting socio-economic costs would be 5.888 million NOK.

7.3.2.2 Bergen – Oslo

Table 13 shows the chosen route from Bergen to Oslo, which is the first transport leg in the intermodal transport alternative 2 mentioned in Chapter 7.1.2. After the arrival in Oslo, the transport for this route is carried out by the Stena Line-ferry “Stena Saga” to Frederikshavn, before it is transported by truck to Hirtshals. The same calculations for socio-economic costs have been applied for this route as for the route from Bergen to Larvik. Table 13 shows the values for km that were used for the calculations for the socio-economic costs on this route. The distances for the different legs on the route are multiplied with the values for socio-economic cost categories from Tables 7-11. This gives the total value of local air pollution, noise pollution, accidents, road congestions and road wearing for the respective areas. Google Maps was used for the distances in Table 13.

Table 13: Distances Bergen - Oslo.

Distance (Bergen – Oslo)	
Bergen – Åsane (large UA)	15 km
Åsane – Trengereid (medium UA)	23,7 km
Trengereid – Bolstadøyri (rural A)	39,1 km
Bolstadøyri - Bulken (rural A)	28,4 km
Bulken – Vossevangen (medium UA)	6,4 km
Vossevangen - Granvin (rural A)	22,8 km
Granvin - Geilo (rural A)	117 km
Geilo - Heradsbygda (rural A)	159 km
Heradsbygda - Skui (rural A)	39,7 km
Skui - Sandvika (medium UA)	6,3 km

Sandvika - Oslo (large UA)	15 km
SUM	**472,4 km**

The obtained total values for local air pollution, noise pollution, accidents, road congestions and road wearing for the respective areas and when summed up for the whole route, are as follows (rounded values):

- Local air pollution: **244 NOK**.
- Noise pollution: **22 NOK**.
- Accidents: **572 NOK**.
- Congestions: **414 NOK**.
- Road wearing: **404 NOK**.
- Total: **1.657 NOK**.

The total value of the socio-economic costs caused by road transport without the consideration of GHG emissions on this route is 1.657 NOK per trip. As done as in the previous subchapter, the total costs were multiplied with the ideal scenario for the Hav Line method, were the reduced number of trucks would be 7.500 annually. In a case, where all of these 7.500 trucks would take the route from Bergen to Oslo, the resulting costs would be 12.431 million NOK.

In another scenario where the Hav Line method only transports 60% of the possible transport volume, the number of reduced trucks would be 4.500. The thereout resulting socio-economic costs would be 7.459 million NOK.

This evaluation also considered a situation where half of the trucks would drive from Bergen to Larvik and the other half from Bergen to Oslo. Caused socio-economic costs here would be 11.122 million NOK per year.

7.4 Central findings of the evaluation

The conducted evaluation of this initial scenario shows that the Hav Line method emits less CO_2 than the two observed intermodal transport alternatives. These results were obtained by applying the mentioned calculation models. The applied calculation models are based on a set of key factors, which were partly obtained from reliable sources, but some of the factors had to be assumed. Naturally, these assumptions can lead to other results, than with actual empirical data. However, none of the observed transport alternatives were favored when it comes to these assumptions. Furthermore, the initial situation was an ideal scenario for the Hav Line method, with a maximum capacity utilization and a transported volume of 1.000 tons.

Further calculations for the emissions of other pollutants, show that the Hav Line method is worse in this regard than the alternatives. These results are based on the higher emission factors for vessels. Euro V and VI trucks already apply efficient engines at present, and therefore it might be always difficult for sea transport options to compete against them, when it comes to the emissions of NO_X, SO_X and PM.

Lastly, a rough estimation of socio-economic costs caused by road transport on the respective routes was shown. Socio-economic costs of the Hav Line method are neglected in this evaluation for various mentioned reasons. These results should be just taken as an indicator of how much socio-economic costs could be eventually avoided by application the Hav Line method.

8.0 Evaluation for a possible extension of the Hav Line method further up in the North

The extension of the evaluation pertains a potential application of the Hav Line method further up North of the Norwegian coastline. Dekkerhus (2017) mentions that the counties of Møre og Romsdal, Trøndelag and Nordland contribute close to 50% of the total production of farmed fish in Norway. Including to the already high production numbers in these counties, it is estimated that there will be a fivefold increase in the production of seafood until 2050 in Norway. This growth will also influence the mentioned regions and lead to an even stronger need for alternative transport options for the export of fresh fish to Europe. Out of 1.300.000 tons of slaughtered salmon and trout in Norway in 2016, 624.000 tons came from Møre og Romsdal, Trøndelag and Nordland. Salmon producers in Central Norway, as in other regions in Norway, apply mostly road transport at present for the export to the European main market (Dekkerhus 2017). It would be therefore interesting to see, if the Hav Line could be a feasible transport solution for these regions.

In one of the email correspondences with Hav Line Gruppen AS, Bård Sekkingstad, the managing director of Sekkingstad AS, addressed the same issue. He came up with the suggestion to evaluate the possibilities of a potential application of the Hav Line vessel further up North in Norway (B. Sekkingstad, personal communication, 01.02.2018) This is a further reason why the evaluation of the Hav Line method was extended to the North.

The selected starting point for this purpose was the island of Hitra (Trøndelag). Hitra is a cluster for the production of farmed fish and the theoretically required transport volumes for the Hav Line vessel should be available. The transport route for the Hav Line vessel goes along the Norwegian coastline from Hitra to Hirtshals. Two intermodal transport alternatives were selected for a comparison.

The main reason for the observation of possibilities for a transfer of the Hav Line method further up North in Norway is to find out, if the Hav Line method can be regarded as a solution that can be applied on a larger scale for most parts of the Norwegian coastline. This chapter was therefore used to answer research question number 3.

8.1 Overview over key factors and necessary assumptions

The sea transport route for the Hav Line method in this scenario leads directly from the island of Hitra to Hirtshals. It was assumed that the average sailing speed of the vessel is again 15 knots. With a given distance of 544 NM in one direction, a one-way trip will require about 36 hours.

Important figures for the route from Hitra for the application of the Hav Line method:

- Average one-way shipping distance: **544 NM** (1007 km).
- Average time required for a one-way trip: **36 hours**.
- Average sailing speed: **15 knots.**

The intermodal transport alternatives in this case are almost similar to the ones in the evaluation in Chapter 7.1.2. The main difference for both alternatives is that the starting point for both routes is now Hitra instead of Bergen. For the intermodal transport alternative 1, the first road transport section leads now from Hitra to Larvik. The part of the route with the ferry link Larvik – Hirtshals is identical. The intermodal transport alternative 2 leads now on the first road transport section from Hitra to Olso. Remaining sections are again the ferry link Oslo – Frederikshavn and the last road transport leg from Frederikshavn to Hirtshals.

Important figures for the intermodal transport route 1:

- One-way road transport distance (Hitra – Larvik): **713 km.**
- Average time required for the road transport section (Hitra – Larvik): **10 hours 45 min.**

Important figures for the intermodal transport route 2:

- One-way road transport distance (Hitra – Oslo): **579 km.**
- Average time required for the road transport section (Hitra – Larvik): **8 hours 50 min.**

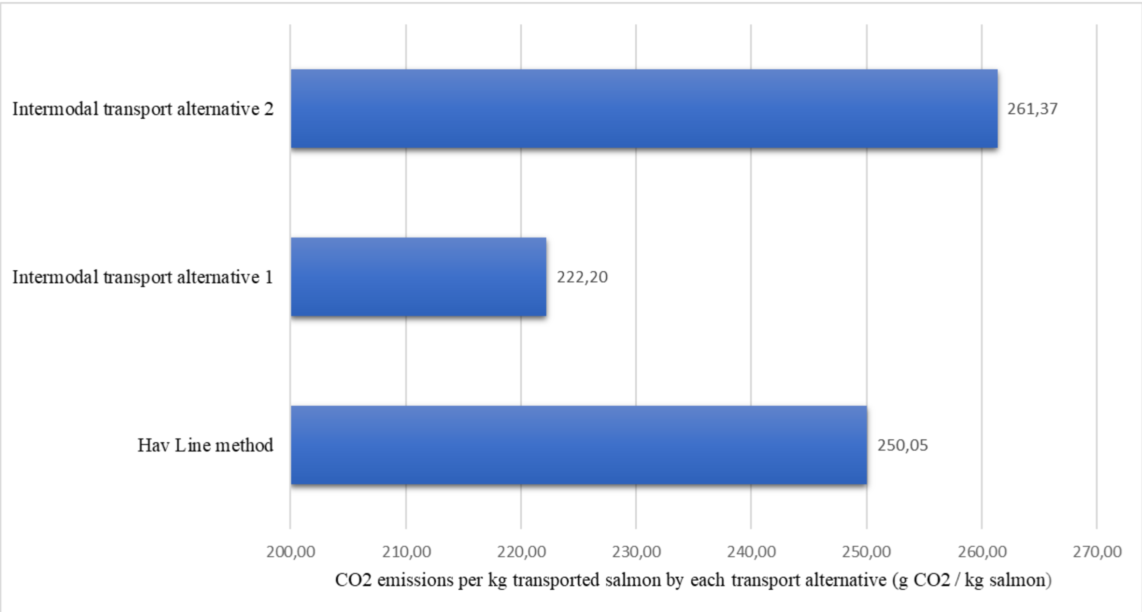
All of the remaining key factors and assumptions that were necessary for the implementation of the calculations for the extension of the route are identical with the mentioned ones in the Tables (2 - 5) in Chapter 7.2.1. These key factors and assumptions pertain applied engines in trucks and vessels, corresponding average engine workloads, values for the specific fuel consumption of engines and load factors for trucks and vessels.

8.2 Applied calculation models and results

The calculation models applied for the extension of the Hav Line method to Hitra were the same as for the evaluation in Chapter 7.2. The obtained results for the total CO_2 emissions of each transport alternative for the transport of 1.000 tons of salmon in this case are as follows:

- Hav Line method: **250.045 kg CO_2**.
- Intermodal transport alternative 1: **222.201,4 kg CO_2**.
- Intermodal transport alternative 2: **261.373,2 kg CO_2**.

It can be already seen from these results that the Hav Line method is not the alternative with the lowest CO_2 emissions in this scenario. Emission values for grams of CO_2 per kg transported salmon for each transport alternative are depicted in Graph 7.



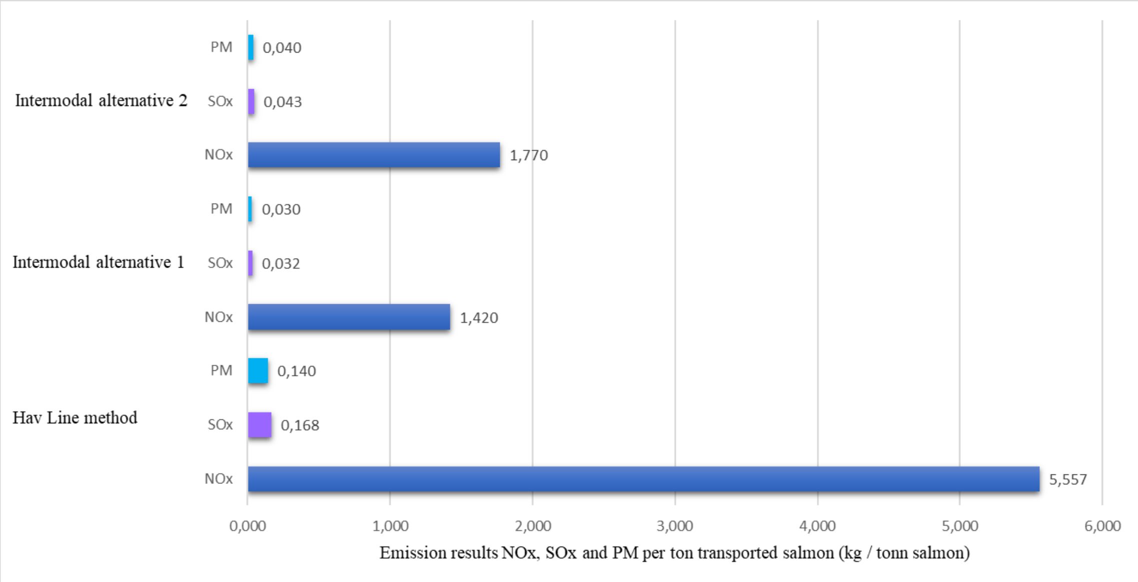
Graph 7: CO2 emissions per kg transported salmon by each transport alternative (extension) (g CO2/kg salmon).

All three transport alternatives have higher values for the average emissions of CO_2 per kg transported salmon in the scenario with a transport from Hitra. The reason for the higher emission values can be traced back to longer distances for all of the routes. However the emission value for the Hav Line method increased by almost 65%, which is the most considerable increase for this value for all of the three transport alternatives. In comparison to that, the CO_2 emission value for the intermodal transport alternative 1 increased by around 20% and the one for the intermodal transport alternative 2 by just 7.5%.

The rather moderate increase of the emission values of the intermodal transport alternatives can be explained by the fact, that the length of their transport routes were not as significant as for the Hav Line method. The road transport section (Hitra – Larvik) of the intermodal transport alternative 1 was 284 km longer than in the initial situation (Bergen – Larvik). The required average time for this section increased by 2 hours and 45 min. The remaining transport via the ferry link Larvik – Hirtshals stayed the same. Intermodal transport alternative 2, with the smallest change in CO_2 emissions per kg transported salmon, had the least significant changes of its route. The road transport section (Hitra – Oslo) is only 116 km longer than for the first section (Bergen – Oslo) in the initial evaluation. Average time required for this part of the alternative is just 1 hour and 20 min longer. The two remaining sections, ferry link Oslo – Frederikshavn and further road transport to Hirtshals stayed the same.

The Hav line method on the other hand saw a major increase in distance and average time required. A complete sea transport journey from Hitra to Hirtshals is 214 NM (396 km) longer than from Bergen. The average time required for a one-way journey rose up to approximately 36 hours from 22 hours. It should be mentioned that a roundtrip of the Hav Line vessel cannot be directly compared to one roundtrip of truck due to the significant difference of the loading capacity. If the loading capacity of the Hav Line vessel is fully utilized, one round trip corresponds to 50 truck roundtrips. However, the empty return trip of the Hav Line vessel in this case is a further contributor to the large increase of the CO_2 emissions value. Due to longer distance in the extension scenario to Hitra, the impact of the empty vessel on its way back to Norway is more severe than in the initial situation with transport from and to Bergen. As for the evaluation in Chapter 7.0, it was assumed that trucks have a loading capacity utilization of 40% on their return legs.

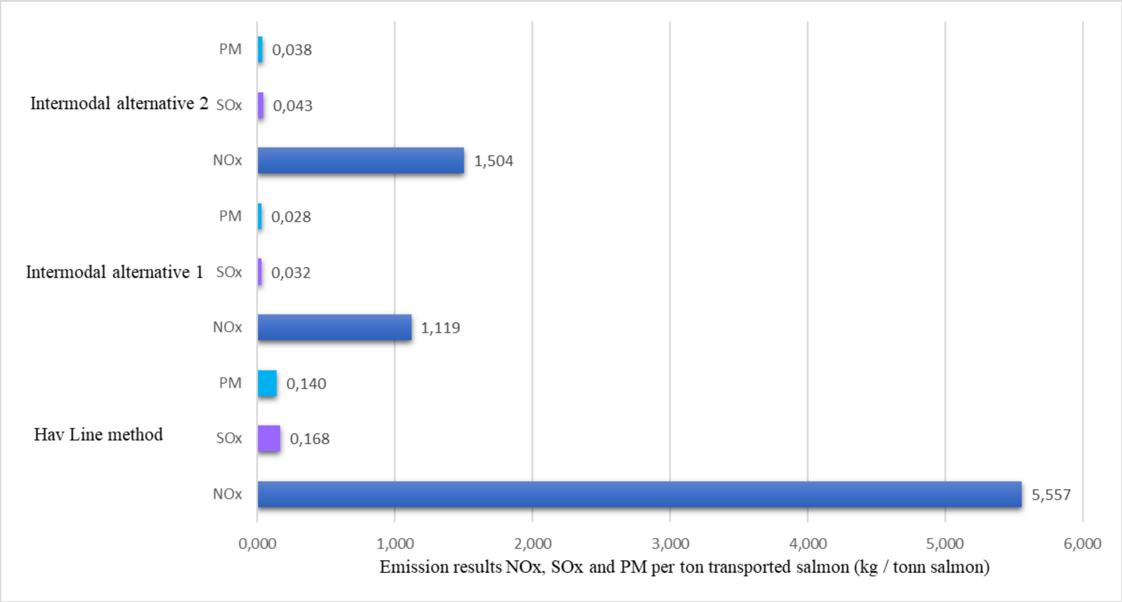
Further results of the route extension to Hitra are depicted in Graph 8 and Graph 9 for the emissions of NO_X, SO_X and PM per ton transported salmon. As for the CO_2 emission values, most of the values for the considered pollutants increased. Thereby, it was also the Hav Line method, which showed the most significant changes, since values for NO_X, SO_X and PM increased by the largest margins. This can be explained by the higher emission factors that were applied for sea transport/MGO-LS than for the Euro V and VI trucks (Table 6). The combination of a route with the most significant change in distance and these relatively high emission factors compared to the ones applied for road transport, led to the worse results of the Hav Line Method in this extension scenario.



Graph 8: Emission results NO_X, SO_X and PM per ton transported salmon for Euro V trucks (extension) (kg/ton).

Graph 8 depicts results for a situation where Euro V trucks are used in both of the intermodal transport alternatives. Whereas the Hav Line method shows significant growths for the emission values of each pollutant, the intermodal transport alternative 1 shows only a considerable growth for the NO_X emission value. Intermodal transport alternative 2 is again the alternative, which is the least impacted by the route change from Hitra to Hirtshals. SO_X emission for all road transport sections were again not taken into consideration and were neglected.

Graph 9 depicts results for a situation where Euro VI trucks are used in both of the intermodal transport alternatives.



Graph 9: Emission results NO_X, SO_X and PM per ton transported salmon for Euro VI trucks (extension) (kg/ton).

8.3 Findings in the evaluation for a possible extension of the Hav Line method

The obtained results from this evaluation for an application of the Hav Line method further up in the North of the Norwegian coastline show a different picture than the results from the evaluation of the initial situation. Based on the applied calculation models, empirical input factors and conducted assumptions, the Hav Line method cannot be regarded as the most environmental transport solution with regard to caused emissions.

The Hav Line method was the most influenced alternative by the conducted changes regarding distances and average time required for the transport legs. Therefore, it also showed the most significant raises for all of the observed emission values. However, it should be still mentioned that intermodal transport alternative 2, which showed the least considerable changes, still had the highest value for emitted CO_2 per kg transported salmon. The emission values for NO_X, SO_X and PM though, were much higher for the Hav Line method than for the two intermodal transport alternatives.

Further factors that were not considered in this chapter are other environmental impacts of the transport alternatives. These impacts can be summarized as external effects of traffic and are for instance noise pollution, accidents and caused damages on the traffic infrastructure. The increased road transport legs of the intermodal transport alternatives would have most likely obtained worse results than the Hav Line method in this case. Therefore, this evaluation should only be used to compare emissions of each alternative and not for the total environmental impact; inclusive caused socio-economic costs by each of the transport solution.

9.0 Discussion

The discussion chapter of this thesis includes a sensitivity analysis regarding the transported volumes of all observed transport alternatives.

Brealey et al. (2011, p. 271) states, that “uncertainty means that more things can happen than will happen. Whenever you are confronted with a cash-flow forecast, you should try to discover what else can happen”. In their definition, they use an example, which concerns a financial aspect. However, a sensitivity analysis can be also used for several other purposes regarding uncertainty. The applied sensitivity analysis in this chapter concerns the transported volumes of the different transport alternatives and how emission values are influenced by different load factors. The applied transport volumes and corresponding load factors in the evaluations in Chapter 7.0 and Chapter 8.0 can be regarded as uncertain input factors to a certain degree. Due to this, other situations with different numbers for these factors are possible and would lead to different results than the presented ones in the respective chapters.

A weakness of a basic sensitivity analysis is that the analysis itself cannot predict anything regarding the actual probabilities of the observed situations. Furthermore, it might lead to ambiguous results and could possibly ignore the interrelation of certain variables (Brealey et al. 2011). Probabilities of the observed scenarios in this discussion were neglected.

9.1 Analysis of required minimum transport volume for the Hav Line method

In both evaluation chapters (Chapter 7.0 and Chapter 8.0), it was assumed that the Hav Line vessel transports 1.000 tons of salmon. This situation was referred to, as the ideal scenario for the Hav Line method, since the available loading capacity to Hirtshals is completely utilized. Such a value cannot be expected on every single trip in the first couple of months or even years of the vessel operation. Therefore, this evaluation was used to find out which transport volumes are necessary for the Hav Line vessel, in order to be equal with business-as-usual transport chains regarding caused CO_2 emissions. In other words, this could be also seen as some kind of break-even analysis for CO_2 emissions.

The applied calculation methods were identical to ones from Chapter 7.2.2. Key factors and assumptions correspond to the mentioned ones in Chapter 7.2.1. The only alteration was made for the transported amount of salmon for the different transport alternatives.

This evaluation showed that the Hav Line method has to transport a minimum of 820 tons of salmon to Hirtshals, in order to emit approximately the same amount of CO_2 as the intermodal transport alternative 1. The average emission value increased from 0.248 kg CO_2/ton-km to 0.303 kg CO_2/ton-km for a respective transported volume of 820 tons of salmon. In a scenario with 820 tons loaded, the Hav Line method would emit about 185 g CO_2/kg transported salmon, which corresponds to the same value for the intermodal transport alternative 1.

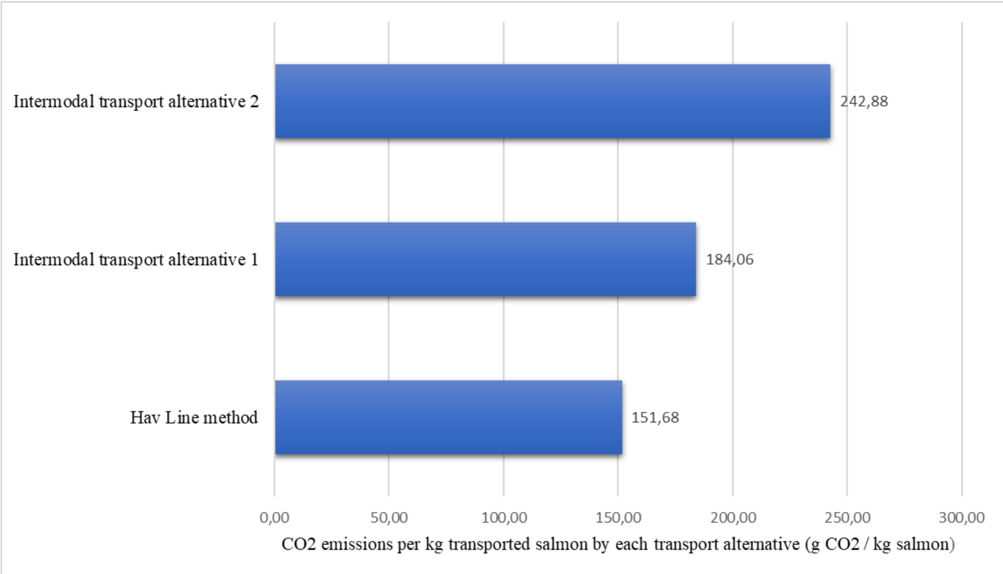
An identical evaluation was conducted in order to calculate the CO_2 break-even volume for a comparison with the intermodal transport alternative 2. The obtained value here for was estimated to be 630 tons of transported salmon. The average emission value increased from 0.248 kg CO_2/ton-km to 0.394 kg CO_2/ton-km for a respective transported volume of 630 tons of salmon. The emission value in this case would be around 240.8 g CO_2/kg transported salmon.

The alteration of emission values for NO_X, SO_X and PM was not observed for the situations with the respective CO_2 break-even volumes. The Hav Line method already emitted more of the mentioned pollutants in the initial situation with transport volume of 1.000 tons, based on the key factors and assumptions. This is due the higher emission factors for sea transport/MGO-LS. Since the Hav Line method is entirely conducted via sea transport, a further growth of these emission values per kg transported salmon can be expected.

9.2 Analysis of the influence of truck loading capacity on return trips

A further input factor that could be easily changed in order to observe its impact on emission values, was the load factor of trucks on their return trip to Norway. It is was assumed in the initial situation that this value is 40% for all trucks. Two scenarios were evaluated and compared against the initial situation. Scenario 1 with a truck load factor of 20% and scenario 2 with a truck load factor of 60% on the return trip.

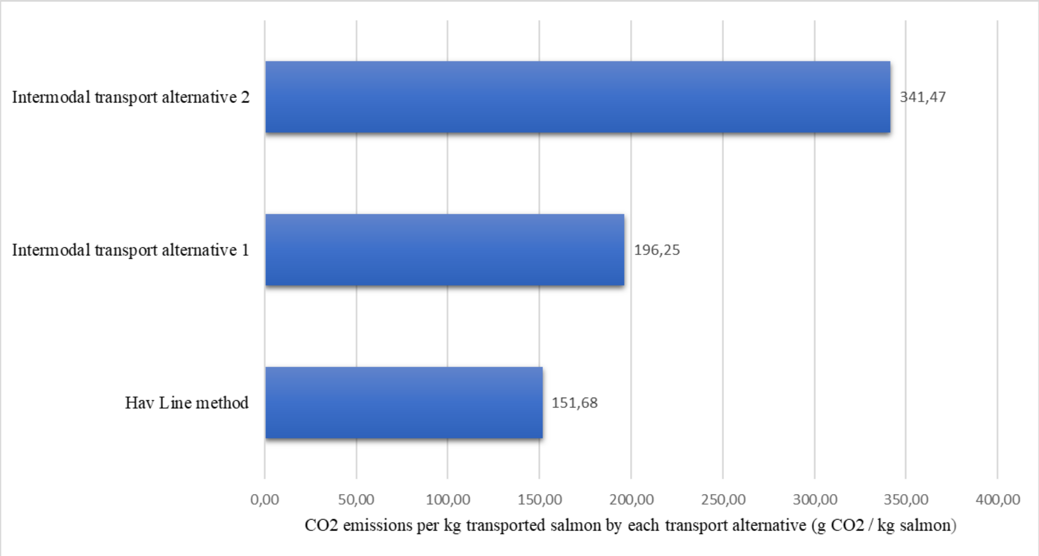
Graph 10 depicts the initial situation, with the obtained results based on the calculation models, key factors and assumptions from Chapter 7.2.



Graph 10: CO_2 emissions per kg transported salmon by each transport alternative (g CO_2/kg salmon).

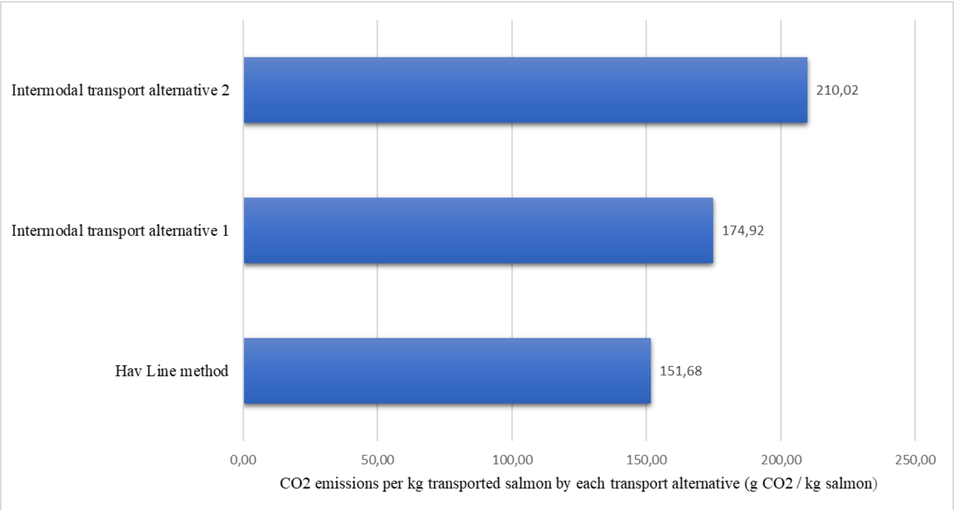
It can be seen that the Hav Line has the lowest CO_2 emission value in the scenario where trucks have load factor of 40% on their return trip. All of the alternatives transport 1.000 tons of salmon in this case.

In comparison to that, Graph 11 shows the results for a scenario with an estimated truck load factor of 20% on the return trip. Both CO_2 emission values for the intermodal transport alternatives increased. Intermodal alternative 1 increased from 184,06 g CO_2/kg transported salmon to 196,25 g CO_2/kg transported salmon. Intermodal alternative 2 increased from 242,88 g CO_2/kg transported salmon to 341,47 g CO_2/kg transported salmon. A significant proportion of the large increase for the intermodal alternative 2 can be explained by the sea transport leg from Frederikshavn to Oslo. As a reminder, this is the transport leg where the Ro-Ro ferry “Stena Saga” uses a higher operating speed than on the journey to Frederikshavn. This relatively high operating speed leads to a higher average engine workload and therefore to a higher fuel consumption of the vessel. In addition to this, the problem of the double load factor of Ro-Ro ferries is now even more significant. An assumed lane meter utilization of 70% and a truck load factor of 20%, lead to an overall capacity utilization of only 14%. As a result of this, the CO_2 emissions per ton-km are much higher than for any other transport leg.



Graph 11: CO_2 emissions per kg transported salmon by each transport alternative (reduced truck load factor on return trip 20%) (g CO_2/kg salmon).

The last observed scenario concerns a situation where the truck load factor on the return trip to Norway is assumed to be 60%. Graph 12 depicts the results for this scenario.



Graph 12: CO_2 emissions per kg transported salmon by each transport alternative (increased truck load factor on return trip 60%) (g CO_2/kg salmon).

Even though both intermodal transport alternatives improved with this assumed load factor, it can be still seen the Hav Line method has the lowest CO_2 emission value of all three alternatives.

10.0 Limitations

The applied calculation models in the evaluation of the Hav Line include a number of assumptions that had to be made, in order to conduct the necessary calculations for emissions and caused socio-economic costs. Some of these assumptions are based on related research issues, i.e. Hjelle (2011), Hjelle and Fridell (2012) or different publications from TØI (Rødseth et al. 2017; Thune-Larsen et al. 2014). These assumptions can be therefore regarded as relatively substantive and are either based on empirical evidence or scientific consensus. Examples here for might be assumed loading factors of trucks on their return trips to Norway or the average engine workloads of applied engine types.

Unfortunately, it was not possible to obtain the same kind of sources for other assumed input factors. An example here for might be the assumed value for the specific fuel consumption of the engines used on the Hav Line vessel. The vessel uses a hybrid version of the mentioned Wärtislä 31 engine. Exact data about the impact of the battery for propulsion purposes could not be obtained and might have changed this value to a certain extend. Therefore, the applied value for the specific fuel consumption was taken from Wärtislä (2015). It would be interesting to use actual fuel consumption values for this engine, measured under operation.

Similar issues concern further assumptions for the specific fuel consumption values of other means of transportation, used in the evaluation.

The estimations for socio-economic costs are rather rough estimations. The impacts of GHG emissions are neglected in this thesis. Comprehensive models that include all kinds of effects that are caused by GHG emission are complex and there is no scientific consensus about the assessment towards human health. Therefore, the presented results should perhaps not be used as exact measures, rather as indicators.

11.0 Further research

In Chapter 8, the evaluation of an extension for the Hav Line method was conducted for emissions like CO_2, SO_X, NO_X and PM. This evaluation can only give answers for the extension of the route to Hitra on an environmental perspective. For further research, a more detailed evaluation of the extension of the route could be done and more possible destinations could be selected.

One example for further research in general, could be to analyze the cost structure of the Hav Line method and compared it against business-as-usual transport. A more detailed evaluation of socio-economic costs through transport related to salmon production would be also interesting.

For the future, it would be interesting to look at how the new vessel has been operating. As mentioned earlier, Hav Line Gruppen AS states that the Hav Line method will be 10%-46% more environmental friendly than the business-as-usual transport (Norwegian Coastal Administration 2017). Further research could evaluate if the Hav Line method is operating as promised, after the vessel has been operating over a longer period.

12.0 Conclusion

The central research aspect of this thesis is to evaluate if the Hav Line method can be regarded as suitable transport alternative for the export of fresh farmed salmon from Norway to the European mainland. Export of salmon from Norway is at present mostly conducted via road transport. Even most of the applied intermodal transport solutions involve large transport sections within the country that are done via road transport. It would be desirable for the sector to change this situation, due to the negative aspects that are linked to the extensive usage of heavy duty vehicles.

In order to answer the central research issue of this thesis, three research questions were selected. The first question deals with qualitative aspects and can be seen as an "introduction" of the Hav Line method. The collected information about this new transport alternative includes facts about the companies behind the project, data about the new vessel, explanations about the planned operation and a basic comparison between the corresponding business-as-usual processes and the Hav Line method. The central finding from the answer to the first research question is, that the Hav Line could lead to significant improvements in the way of how the export of fresh farmed salmon is done today. Shorter overall lead time, reduced costs and fewer environmental impacts are the main advantages that should be mentioned here.

The gathered information from the first research question, was essential for the answer to the research question number two. This question concerned the actual environmental performance of the Hav Line method, more specifically emissions and socio-economic costs associated with salmon transport. It was answered by applying a quantitative methodology and comparing the performance of the Hav line method against two business-as-usual transport alternatives. The applied calculation models show based on the used input factors and assumptions, that the Hav Line mehtod can be more environmental friendly in certain areas than the usually applied transport operations. This better environmental performance pertained the emission of CO_2 and caused socio-economic costs. However, for other emission factors like NO_X, SO_X and PM, it is shown that the observed transport alternatives are "cleaner" and their application leads to lower emissions of the mentioned pollutants.

The last research question evaluated a possible application of the Hav Line method in other areas than the currently planned parts of the Norwegian West Coast. The selected new route for the vessel goes from Hitra to Hirtshals. Results of the conducted calculations show that this extension wouldn’t make much sense regarding emissions, since one of the observed intermodal transport alternatives has better results than the Hav Line method. These results are however based on a number of assumed factors. Empirical data from the actual vessel operation might provide different results. Furthermore, socio-economic costs are not considered in this evaluation.

Conclusively, it can be said that the Hav Line method can be regarded as an innovative project that might be one of the future solutions for the export of fresh farmed salmon from Norway to Europe. There are some aspects that could not be completely answered in this thesis, but the central evaluation of the method shows that the Hav Line method can be seen as an alternative to business-as-usual transport for salmon export.

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