Master’s degree thesis

LOG950 Logistics

The impact of changing cooling refrigerant in fresh whole salmon export to dry ice

Even Spilling

Number of pages including this page: 65

Molde, 23.05.2022

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Preface and acknowledgements

Back in 2016 I had just finished conscription in the Air Force. I had no idea what I wanted to do. I even counterplayed enlisting for the army whilst finding out what I wanted to do. After a year working part time and traveling, I decided to take a shot at logistics at the Molde University Collage.

After 2,5 years we were ready to write our bachelor thesis. Then it happened. Lockdown. The coronavirus pandemic has made things challenging for us. Especially for the master class of 2022. We experienced full lockdown during most of our bachelor thesis. We experienced classes, meetings and exams being transferred online. The student life was almost erased. Not only did we have to adapt to a new way of working, many students entered a labor market in crisis.

The pandemic made the decision for me to continue at Molde University Collage. Looking back, I am grateful for continue to the master program. My fellow students and I are seemingly sought after, and most of us had no problem acquiring a job during our last semester. This underlines todays situation in Norway and the world. Increased raw material-, labor- and transportation costs has led to companies to focus on optimizing their business processes. And this is where we, the master class of 2022 comes in to play!

It has been 20 years since I first started at primary school, 18 years of school that are ending. I am excited to start a new chapter working in the ERP business in August.

A big thank you to my supervisor, Vikenco, sources and fellow students that have helped me with the master theses!

May 2022, Molde

Even Spilling

Abstract/Summary

The Norwegian seafood industry is globally acknowledged as one of the best. High quality products are served all over the world. From sushi restaurants in Tokyo to cruise ships in the Caribbean. Norway is the largest Atlantic salmon farmer in the world, producing approximately 1,3 million tons in 2021 (Kyst.no, 2022). Norway’s coastline and deep fjords has made it optimal for fish farming.

Norwegian farmed salmon are experiencing a growing demand worldwide. Difficulties in meeting the demand for high quality Atlantic salmon has sparked all time high export prices the spring of 2022. The seafood industry is the second most valuable export industry after petroleum for Norway.

Despite the favorable prices, the industry is facing multiple challenges. The coronavirus pandemic has increased raw material- and transportation cost. The war outbreak in Ukraine has also made it more difficult to export salmon towards the Asian markets. On top of these challenges, we are in the thick of a climate crisis.

Norwegian seafood exporters need to investigate their own transport chain. Thousands of trucks drive off every year towards the markets. The Norwegian Public Roads Administration has acknowledged that water spillage from salmon trucks has become a problem on Norwegian roads. The Minister of Transport has commented that new regulations are on the table to ban all spillage. This means that the salmon exporters must either implement solutions to prevent the spillage or change cooling refrigerant.

“Sustainable aquaculture, a source to feed the world” is one of UNs goal to fight hunger in a sustainable way. With the resources within the Norwegian state and seafood industry, can and should be leading the way with innovative solutions to reach UNs goal.

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1.0 Introduction

Norway's long coastline and deep fjords make it a perfect location for fish farming. Salmon has become the most important product in the Norwegian seafood sector. According to Statistics Norway, Norway exported 1,05 million tons fresh salmon in 2021. With an average price of 59,23kr/kilo, the total export value is 62,03 billion NOK. One of the problems the industry is facing is the rising cost of transportation. In this thesis I will investigate the outcome if the industry were to switch cooling refringent from traditional wet ice to dry ice, and what will the environmental impact be. In addition, I will discuss the potential future of the industry, and what may affect the future transport chain.

During the research design seminar, we were tasked to write a proposal to get some experience on how to write a proposal. Since I had a topic ready, one was able to use this seminar to start writing the proposal.

In May 2021 I got a part time job at Vikenco AS. Vikenco is a processing plant for fish, primarily salmon located in Aukra county, just outside Molde. One of my selling points during the interview phase was that I could write a master thesis for the company. Since I was hired, I have spoked loosely about potential problems that I could investigate. Then I heard about the use of dry ice as a cooling refrigerate during transport of salmon fillets overseas. Vikenco calls this Vikenco SuperGreen®. Since the beginning of the project, there has not been gathered much data on how much the company saves by using dry ice, and how much it affects the CO_2 emissions in the supply chain. Not all salmon exported is fillets, the majority is in fact whole. For whole fish, wet ice is used as cooling refrigerant. However, some exporters have started to use a hybrid of dry- and wet ice. The main reason why wet ice is mainly used, is that when experimenting on usage of dry ice the gills are discolored. The color of the gills is regarded as a quality mark. It is uncertain why the dry ice causes this damage.

1.1 Today's transport chain

In 2020 Norway exported 1,1 million metric tons of salmon (Nilsen, 2021). Most of the salmon is driven from plants in Norway to the European market. Salmon for America or

Asia is driven to major airports with good connections, such as Oslo Airport, Heathrow (London), Schiphol (Amsterdam) and Helsinki Airport. The goal is to deliver fresh salmon to customers all over the world within 4 days. To keep the product cool and fresh under transport it is necessary to use ice. The ice consists of about 20% of the total transport weight. This of course affect the transportation cost for Norwegian salmon companies. After the outbreak of the coronavirus, air freight rates increased up to 200%. In recent news, we also hear that it is a deficit of trailer drivers in Europa. These factors have made it increasingly important to minimize transportations cost.

Some Norwegian processing plants have started to produce dry ice as cooling refrigerant to transport salmon fillets. Dry ice is CO_2 in solid form. After applied, it cools the product down faster and cooler than traditional ice. The product reaches a stabile temperature of -1 to 0 degrees Celsius.

After a couple of hours, the dry ice vaporizes to gas form, CO_2. This means that where traditional ice melts to liquid form (H_20), the weight is still in the boxes. This gives us the opportunity to save up to 20% of the transport weight.

A different aspect is that the usage of dry ice avoids water spill from the lorries transporting the fish from plant to customer/airport. Water spill on roads has been a focus area for Statens Vegvesen (Norwegian Public Roads Administration, or “The Road Administration”) in Norway, and will continue to be in the future. Eliminating the use of wet ice can potentially decrease transportation costs and reduce CO_2 emissions from road- and air freight.

The salmon industry has been a hot topic last autumn in Norway for several reasons. One of them is that salmon export price is all-time high.

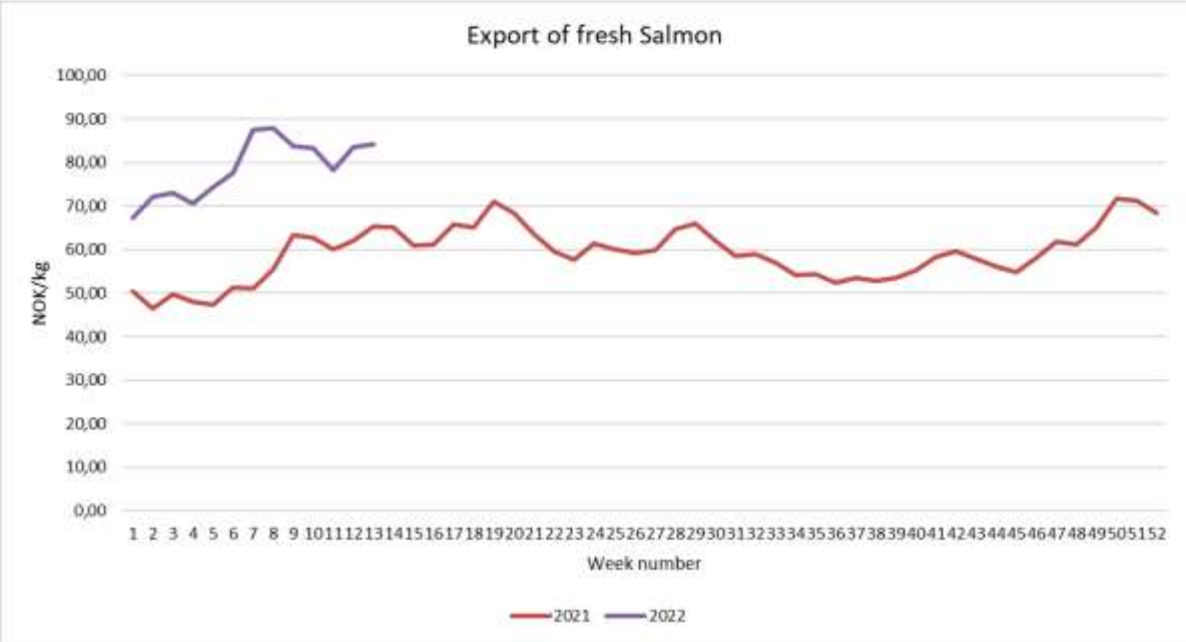

Figure 1: export price at end of week 2021-2022 (Statistics Norway, 2022).

The key reasons for these high prices are lower biomass and increased transport cost. According to Norwegian Seafood Council numbers for March 2022, the export volume was 7% lower than 2021. The price was 32% higher than in 2021. This resulted in an export value of 8,4 billion NOK, an 19% increase from 2021 (Norsk Sjømatråd, 2022).

Despite the high export prices, transport costs are chewing off a big part of the increased value. The Russian invasion of Ukraine in February 2022 led to sanctions against air traffic. This meant that the air traffic to Asia has been much more complex. According to Ocean Supreme director Botholf Stolt-Nielsen the transport costs to Asia has doubled since the invasion (editorial staff iLaks, 2022).

In February 2022, an article from national broadcaster NRK stated that The Norwegian Public Roads Administration wish to go after the Norwegian salmon exporters because of excessive spillage (Hunnestad, 2022). According to the article, the load maintains too high temperature and thus causes a mixture of melt water and blood to flow off the trucks. The Road Administration believes that this causes a traffic hazard, especially during the winter month when spillage settles as ice on the roads. The Minister of Transportation, Jon-Ivar Nygård said “It is forbidden, and when something is not legal, the carriers must comply with the law. This means that they must sharpen up and stop causing spillage on the roads”. In 20 weeks in 2021, the Norwegian Public Roads Administration handed out more than 400 driving bans due to spillage. National interest organization Seafood Norway stated that the responsibility is divided between the seafood companies and the transporters. As of today, the Road Administrations mandate is only to hand out driving ban on first offence. To be able to go after the seafood companies as well, the Road Administration has initiated a cooperation with the police to find out if they can sue the exporters as well.

Figure 2: Spillage, Statens vegvesen, 2020 (Ersfjord, 2020).

This article clearly demonstrates that both the seafood industry and transport companies should take actions before action is against them.

1.2 Research question

What impact will the usage of dry ice as cooling refrigerant have on transport of whole salmon overseas?

A quick estimation by Vikenco is that Norway export 200.000 metric tons of whole salmon by air freight every year. Knowing that up to 20% of the weight is ice, we can estimate 40.000 tons of ice being transported annually. Given a rate of 25 NOK per kg, that is 1 billion NOK excessive air freight cost. According to Vikenco, the main reason why dry ice for whole salmon has not been implemented yet is the uncertainty around quality. Is it possible to prove that dry ice can maintain the same- or better quality? It’s also important to make sure that both customer and third-party logistics partners accept the usage of dry ice.

During the meetings with Vikenco we also discussed that there is not much data on the impact dry ice usage for fillets have had. A potential research question is what the economic and environmental impact it is to substitute wet ice with dry ice for fillets transported abroad (USA, Canada, Japan). The aspects of this question include several areas in the transportation chain. Norwegian suppliers need to obtain the infrastructure to use dry ice. Gas tanks, dry ice machine and sufficient ventilation to keep the CO_2 levels in the facility within requirements. Production cost of making dry ice versus wet ice also need to be calculated to be able to compare the two solutions. Reduced weight will reduce emission from both trucks and air freight. Trucks are limited to weight. Therefore, reduced weight can potentially increase volume sent and reduce the required number of trucks per year. Wet ice is causing water spillage. This water spillage is spilled on roads, in storage and in planes cargo haul. Waters spillage on roads can cause accidents and reactions from road authorities, such as fines and delays. A potential sub-problem can be if it is possible to use captured CO2 in the production of dry ice. This can further reduce the CO_2 emissions.

Will new legislation force the exporters and/or transporters to adjust their transport chain?

There are several suggestions on how to coup with the spillage problem. One of the suggestions is to make it mandatory to use clogged boxes with an absorber. It is also possible that the legislators could ban all spillage. This would mean that exporters and carriers together need to cooperate to eliminate all future spillage.

2.0 Literature Review

The Norwegian salmon industry has been under the spotlight for quite some time for a variety of reasons. Therefore, there are a lot of research done be Norwegian institutions. Reports from SINTEF and Avinor have been important sources. SINTEF is one of Europe's largest independent research institute. SINTEF have done a lot of research on the climate footprint from the industry. Avinor is a state-owned company under the Norwegian Ministry of Transport and Communications and is responsible for serving airports and air traffic in Norway. Since salmon has become a large export success for Norway, Avinor are interested in mapping the outbound seafood logistics to markets outside Europe.

Through the library's resources I have been able to find two former master theses that explore cooling of fresh salmon. Both theses are written by students at Norwegian University of Life Science NMBU. It is also worth noting that both theses had the same supervisor and same contacts at Tine FoU (Tine Research- and development department).

"Optimization of solutions for distribution of fresh, chilled salmon" research the cold chain for salmon from processing plant to stores, using different amounts of dry ice, and different cardboard packaging (Stuve 2012). This paper has examined temperature during transport with dry ice applied. Data from this paper may be used to provide proofs that dry ice can be used to maintain the quality.

"Optimization of the cooling chain" is the other paper. The purpose of the thesis is to document the cooling chain for dry distribution of fish, based on the cooling chain for SALMA®, and consider whether the cooling chain was optimal or not (Egeland, 2012).

In addition, the resources at Vikenco will be important. Vikenco was among the first fish processing plants in Norway to implement dry ice usage. Some of my colleagues has 20 years of experience at Vikenco and will be good sources for information.

To investigate the transport chain, I did speak with some of the stakeholders. I have been able to speak to representatives with different interests.

2.1 Meetings with Vikenco

Vikenco is a supplier of seafood to markets in Norway, the Far East and USA since 1973 (Vikenco AS, 2022). Vikenco has a harvesting plant in the ocean gap on Gossa island. The main product harvested is Atlantic salmon.

In the meeting there were presented an interesting statement: “Each year about 200 000 metric tons of fresh whole salmon is exported by air freight. This means that if we estimate 20% wet ice as cooling refrigerant, an estimated 40 000 tons of wet ice is transported as well. Given a total freight cost of 25 NOK/kg, that’s 1 billion NOK excessive freight cost for Norwegian salmon exporters annually”.

Vikenco together with Nippon Gases Norway collaborated to create the SuperGreen™ concept. The specific details in the concept are labeled cooperate secret, but the main features are described on both Vikenco` and Nippon Gases website. Vikenco has experience with super cooling, or superchilling, since 2000. Vikenco`s investment in the SuperGreen concept have made it possible to deliver fresh, cooled and dry packed salmon worldwide. According to Vikenco`s web site the usage of dry ice has increased the products shelf life, which will provide the importers a longer window to sell and consume the product.

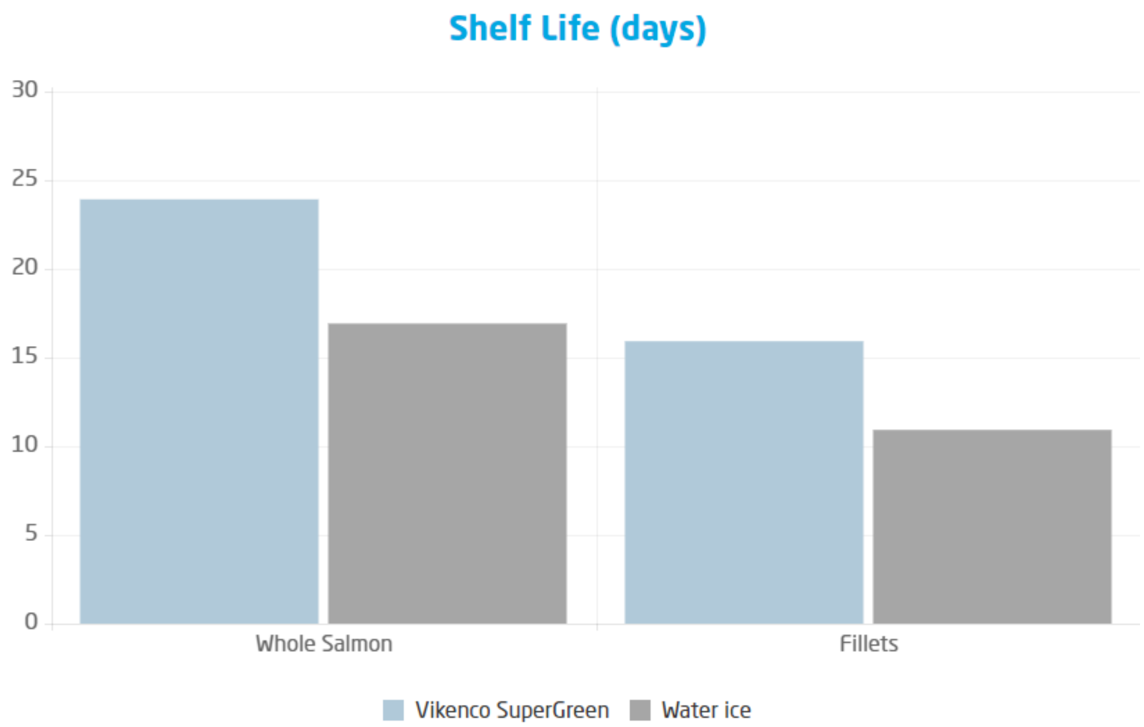

Figure 3: Shelf life (days) Vikenco SuperGreen vs. wet ice (Vikenco AS, 2022).

The SuperGreen concept on paper seems like a better cooling refrigerant than wet ice. However, Vikenco has faced the same problem as other vendors when applying dry ice on whole salmon, discoloring on the gills. This has prevented SuperGreen to be the only cooling refrigerant used. If the cause of discoloring is found, and the problem can be solved, fish exporters like Vikenco would easier be able to implement dry ice as the only cooling refrigerant used.

2.2 Meeting with Nippon Gases Norway

Nippon Gases is an industrial gas supplier founded in 1918 in Japan. They are the fourth largest industrial gas provider in Europe with 9% market share. Nippon Gases have invested heavily towards Norwegian fish farming and aquaculture. Nippon Gases deliver oxygen to land-based fish farms to optimize growth and fish welfare. Another product they deliver to the industry is liquid carbon dioxide (CO_2). In collaboration with Vikenco, Nippon Gases created the concept of using dry ice as a cooling refrigerant. This concept is known as SuperGreen™. This concept has proven efficient especially when air freight is used, as it reduces the weight. The usage of dry ice is increasing, and new processing plants that are being built facilitate the infrastructure needed to use dry ice. In addition to sell oxygen and carbon dioxide, Nippon Gases are also selling complete systems for the use of dry ice.

During my meeting with a representative of Nippon Gases Norway, I was given an interesting description of the seafood industry from their point of view. In addition, I was provided with different sources of information regarding the use of dry ice/superchilling-method (SuperGreen™).

The representative described the seafood industry as traditional, and that the industry is not frontrunners when it comes to innovation. Per 2022, the prevalence of the use of dry ice is still limited, despite more knowledge and information suggesting that dry ice is a better cooling refrigerant than traditional wet ice. According to a SINTEF report from 2014, 12,9% of all pollution related to the Norwegian seafood industry is intercontinental air freight (Hognes, 2014).

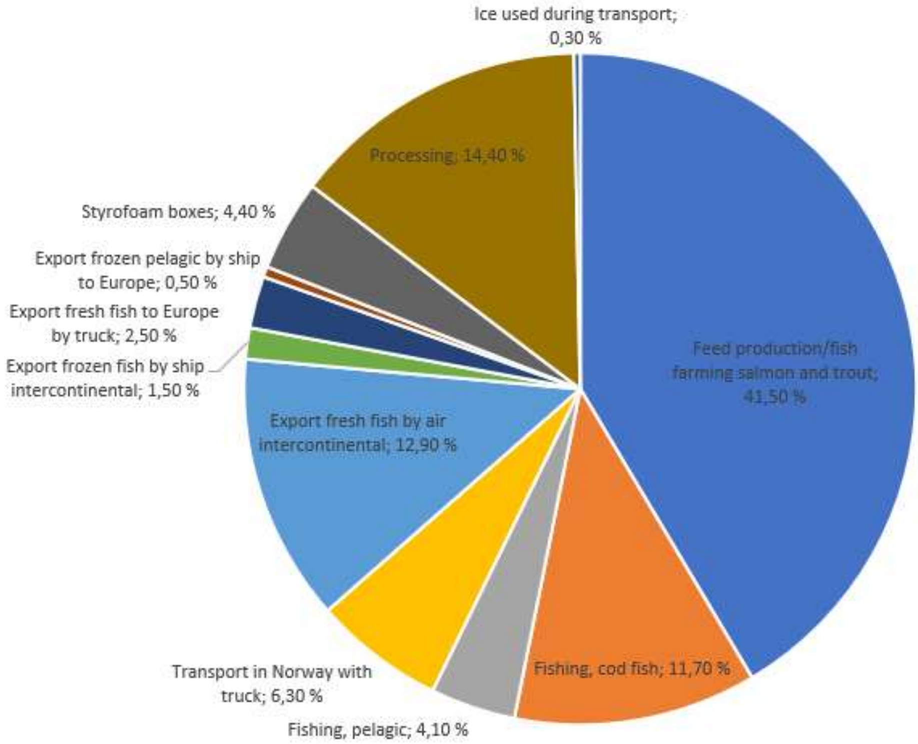

Figure 4: Pollution from the Norwegian seafood industry (Hognes, 2014).

In the same report the total pollution is estimated to be 8 284 609 tons CO_2 equivalents. Intercontinental export of fresh salmon will then account for 1 066 732 tons of CO_2 equivalents. According to Nippon, 1 kg of wet ice transported to Japan results in 10 CO_2 equivalents. This means that if the industry substitute wet ice with dry ice, you could reduce transport weight up to 20%, thus reducing the pollution and transport costs similarly.

As previously mentioned, the salmon industry has started to open its eyes to the use of dry ice as a cooling refrigerant. Especially fillets are being transported with dry ice, because of the increased air rates. Whole salmon however are still mainly chilled with wet ice. This is due to the perception among customers that dry ice reduces the quality of the fish. According to Nippon, approximately 70% of salmon exported intercontinental is whole salmon, but the demand for fillets is increasing and will account for a larger share in the future.

Another factor that has become more important in 2022 is electricity consumption. According to Nippon it is estimated that you need 0,5 kW of power to produce 1 kg of wet ice. In addition, you need access of large quantities of clean water. When asked how economically dry ice contrasts with wet ice, Nippon suggested that dry ice is more expensive to acquire, but the potential savings on transport costs will make dry ice the best economical option, without giving specific numbers on dry ice costs. What I did learn is that Nippon Gases Norway have been capturing carbon at their facility in Porsgrunn, Norway. The most energy-intensive step in the process is to compress CO2 into liquid.

An interesting comment from Nippon was that due to the use of wet ice, and the spillage that occur at the start of the transport, there are rumors in the industry that trucks are being sent from processing plants overweight, calculating that enough spillage has runoff before they are potentially controlled by The Norwegian Public Roads Administration. If this is true, The Norwegian Public Roads Administration and the law makers should have a strong incentive to both step up controls, and to potentially change legislation to make sure that traffic safety is maintained. I will discuss the potential problem in a later chapter.

2.3 Meeting with The Norwegian Public Roads Administration

My main reason to speak to The Norwegian Public Roads Administration was to find more data on spillage from fish transport. After the meeting with Nippon Gases where I learned about the rumor of overweight transportation, I also wanted to speak with The Norwegian Public Roads Administration to find out what they knew.

A representative for central Norway described their zero vision, and that it is important for the road administration to prevent spillage to cause accident in the future. The representative described an unhealthy competitive environment among transport companies. The fierce competition has led to low margins. Some companies give drivers incentives to drive as fuel efficiently as possible to save costs. To save fuel, the Road Administration has noted during controls that drivers intentionally increases the temperature in the carriage. This will cause the water ice to melt faster and spillage to occur more rapidly. The representative points to unhealthy competition in the transport industry with small margins as an explanation to this practice.

The Road Administration recommended to contact ferry companies in Norway to further map the consequences of spillage. Fjord 1 is the leading ferry company in Norway, with 79 ferries and approximately 16 million passengers per year (Fjord 1 AS, 2022). Fjord

1`s core business area is western Norway. In a short comment from Fjord 1, they acknowledged the problem. They stated that spillage from salmon transports contaminate the car decks on the ferries, and the ferry piers. This spillage causes bad odor and discomfort for the passengers who may step in the spillage. Because of tight schedules, the crew do not always have time to flush the decks after each trip, causing the spillage to sustain on the car decks longer. Fjord 1 did not have any data that mapped the economic consequences of the spillage. Fjord 1 also stated that they have refused to transport trucks with spillage. This has led the salmon exporters to contact Fjord 1 to express their dissatisfaction with their logistics being hindered. Fjord did add that the problem seems to be less frequent now, compared to a few years ago, without elaborating much more. The impression of Fjord 1 is that they do not want spillage on their vessels and are willing to act if spillage is observed before trucks have boarded.

According to a recent article the Norwegian Minister of Transport Jon-Ivar Nygård stated: “The Norwegian Public Roads Administration have been in contact with the seafood industry, the Norwegian Food Safety Authority, police and the Norwegian Truck Owners` Association in recent years, debating the water spillage problem and potential solutions. However, controls show that it has not been any improvements. We must therefore consider tightening the regulations, including more effective sanction options to prevent spillage” (iLaks, 2022).

2.4 Superchilling

Superchilling refers to the process of cooling food to sub-zero temperatures. The ideal storing temperature for fresh fish is 0°C. The number of biochemical and microbial reactions are decreasing when the fish hold this temperature. The low storage temperature will also decrease the growth of microorganisms. These reasons are providing a longer shelf life for the product (Stuve, 2012).

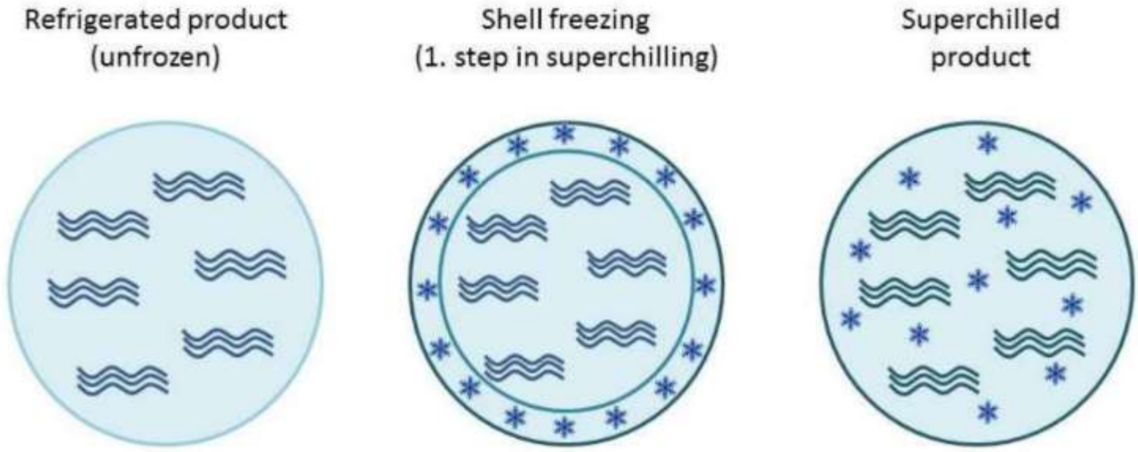

Figure 5: The different steps in superchilling of food: The present water in the product is partially frozen and after a certain time mixture of water and ice is present inside the structure of the product (Bantle, 2016).

2.4.1 Dry ice

Dry ice is CO_2 in solid form. It is produced by pressurizing liquid CO2. The product is often made in pellets. Dry ice keeps its form when the temperature is below -78,5 degrees Celsius. Dry ice is mainly used as an industrial cooling refringent, due to its superior cooling performance over traditional wet ice. Due to the lack of humidity, the dry ice also kills bacteria and therefor has a preservative effect.

Dry ice sublimate when heated. This means it goes directly from solid to gas form. This property makes dry ice optimal for road- and airfreight. Unlike traditional ice, the weight of the cooling refringent is vaporizing, decreasing transport weight, but keeps the product chilled.

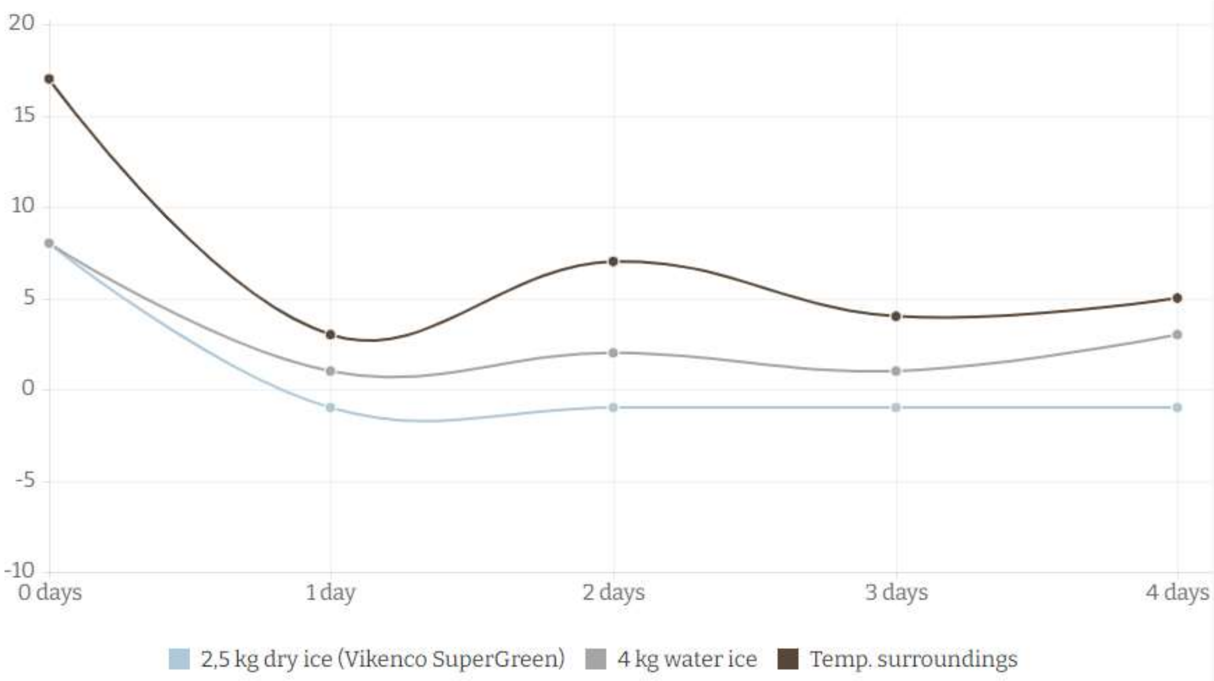

Figure 6: Transport from Norway to USA, Vikenco SuperGreen vs water ice (Vikenco AS, 2022).

The graph above shows how dry ice performs against wet ice according to Vikenco©. When sublimating the dry ice cooling energy transfer into the product itself, which makes it its own cooling element. The protein in salmon has a freezing point around -1°C to -2,5°C. The product can therefore sustain being super chilled at around -1°C without cell rupture and drip loss due to freezing (Egeland, 2012, p. 20).

According to a study conducted in 2003, Fresh Atlantic salmon fillets stored super chilled at -2°C had a 21-day sensory shelf life, whereas normal chilled fillets at 4° was spoiled after 7 days (Sivertsvik, 2003).

Nippon Gases could not provide the cost of implementing dry ice infrastructure, since this is labeled cooperate secret. They did however state that the investment will pay off within short time, due to transport cost reductions.

3.0 Case Description

3.1 From the ocean to the customer

Norway's long coastline with many deep fjords makes it the perfect location for fish farming. When the fish is ready to harvest, it is transported to a processing plant, mainly by blubber boat. At the processing plant, the fish is transferred to waiting cages outside the plant. From the waiting cages, the plant can vacuum in the fish by tubes into the plant. The fish will be processed according to customer orders. Products varies from whole salmon to different trimmed fillets.

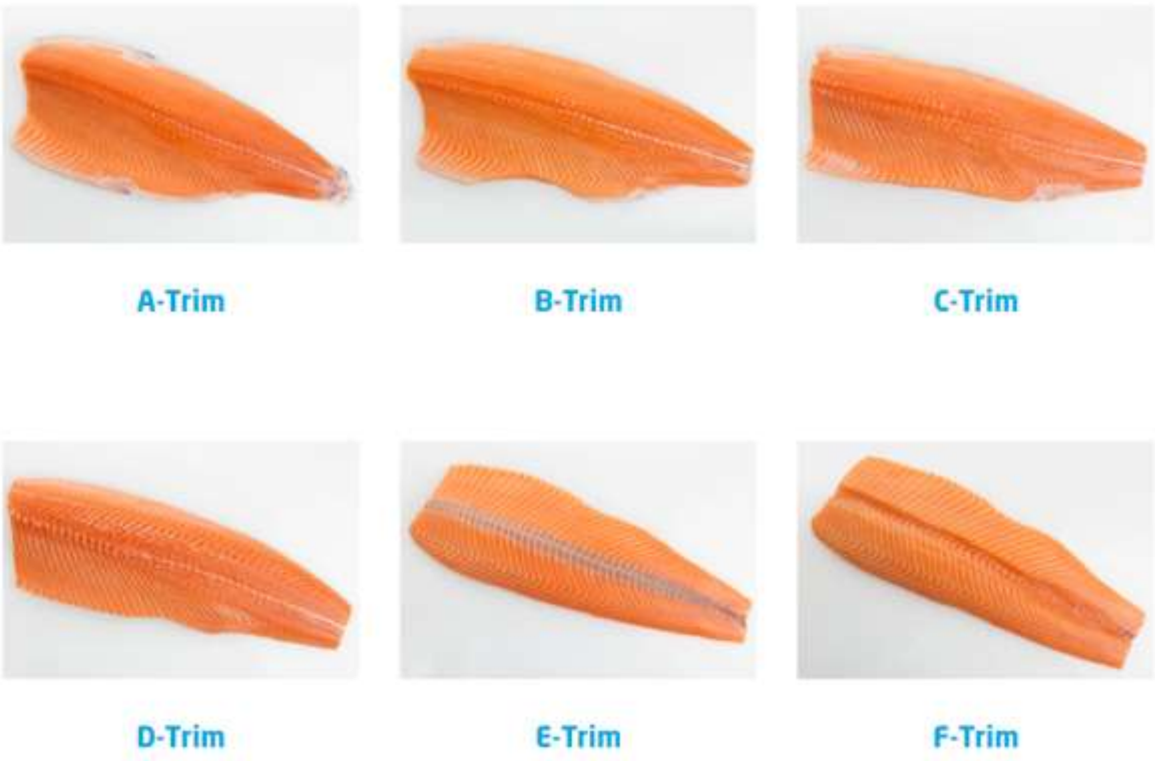

Figure 7: Salmon Products (Vikenco AS, 2022).

When the fish is processed it is stacked in EPS boxes made especially for fish transport. EPS boxes is made of expanded polyester, or styrofoam as it is also called. This is the preferred material used to make boxes for transportation of seafood, due to its low weight. The 20 kg box is considered the standard box in salmon industry. It weights around 600 grams and can transport, as the name indicates, around 20 kg each. The boxes are by description clogged. It is vital that the boxes do not get overfilled. This would cause problems when sealing the box. If the box is not sealed correctly, the box will not be entirely sealed, and this can affect the products quality during transport.

Before the boxes are sealed, ice is applied. The amount of ice may vary, but around 20% of the total weight is ice. The boxes are stacked on euro pallets and then loaded on trucks for transport. The goal now is to get the fish delivered to the customer as soon as possible.

When using air freight, the cargo needs to be reloaded onto air freight containers, called PMC. If the boxes are properly dense, most of the melted ice is still in the boxes. This means that there might be up to 20% water being transported. Incoterms can vary among customers and suppliers in Norway, but my experience is that DPU (Delivered at Place Unloaded, Incoterms 2020) is a common Incoterms for intercontinental transport of fish.

3.2 Statens Vegvesen

Statens Vegvesen (SV) is the Norwegian Public Roads Administration. Their responsibility is to plan, build and maintain the road network in Norway. SV is also conducting vehicle controls along with other agencies. In 2002 the Norwegian parliament adopted the "zero-vision". The zero vision is the ambition of 0 killed and 0 badly injured in road traffic. In 1970 there were 560 killed in road accident in Norway. In recent years the number has been around 100. One of SV`s important strategies to work towards the "zero vision" is to prevent accident through traffic controls. An issue that has received more attention in recent years is water drainage from fish transports. In conversations with SV they can confirm that this in now a focus area for the controllers, especially in middle Norway where most fish transport travels towards the world market. As of now, the SV do not have any evidence that someone has been killed- or badly injured related to water drainage. Although, SV has acknowledged that water spillage can create a traffic- and environmental hazard. One example is icy roads due to water spillage during winter. An environmental example is that in addition to water, the drainage can contain blood. This spillage has the potential to locally contaminate along the road, on board ferries and at rest stops.

In 2021 SV started to map water spillage from fish transports nationwide. It is important to note that SV controls are random, not constant, and mostly at own test stations. The controls also vary in duration. This means that there are large dark number. Between week 16-35 and 40-52 in 2021, 279 driving bans were given out in middle

Norway. A driving ban in this regard is when there is any spillage from the cargo (fish). A driving ban is the only reaction SV have authority to use when spillage is found. To stop the spillage the driver can decrease the temperature, to stop the wet ice from melting. SV have noted that some drivers deliberately drive with higher temperature then optimal to save fuel. This might be due to very low margins for transport companies, so they are incentivizing drivers for saving fuel. SV can inform that is has occurred that the same truck gets stopped twice. When this happens SV can sue the driver for failure to comply with SV guidelines. With today's laws/regulations SV don't have the authority to react against transport companies or transport customers, regarding the spillage, but they are in close contact with law enforcements to discuss how they can fight spillage. At the moment, SV cannot confirm if the parliament is working on new regulation, but they do welcome changes that can make it illegal. An example is the Faroe Island, where it is forbidden for all fish transport to have any water spillage.

3.3 Fish farming in Norway

The three primary species for farming in Norway are salmon, trout and sea trout. Combined they account for 97,5% of the total volume in 2017 (Misund, 2021). In 2017, the industry had over 65 billion NOK turnover. More than 61 billion, or 94,14% of the value was Atlantic salmon. Most of the farms are spread out along the west- and north coast of Norway. Processing plants are located to minimize distance from fish farms, and to have ideal prerequisites to host fish in waiting cages. Since the ideal location for fish farming is where it is, there are some logistical challenges. Fresh Atlantic salmon is considered a premium product that consumers are willing to pay high prices for if the quality is satisfactory. This means getting the product to the consumers as soon as possible is crucial. Almost all sold product travel to or through either Oslo or Helsinki. This means transporting tons of product on thousands of trucks through Norway. The product transported to Helsinki are mainly transported abroad with the good connections to Asia from Helsinki Airport (HEL). Oslo is more of a pre-carriage hub, where product is reloaded to new trucks. Much is transported directly to customers in Europe. Some are transported to major air freight hubs such as London-Heathrow, Schiphol-Amsterdam or Kastrup-Copenhagen to be distributed overseas, mainly to the US and Canada.

Figure 8: Fish farm locations in Norway (BarentsWatch, 2022).

According to Kyst.no, The cost of producing 1 kg Atlantic salmon in 2020 was 40,15 NOK, up 4,9% from 2019. The numbers are collected by the Norwegian Directorate of Fishery.

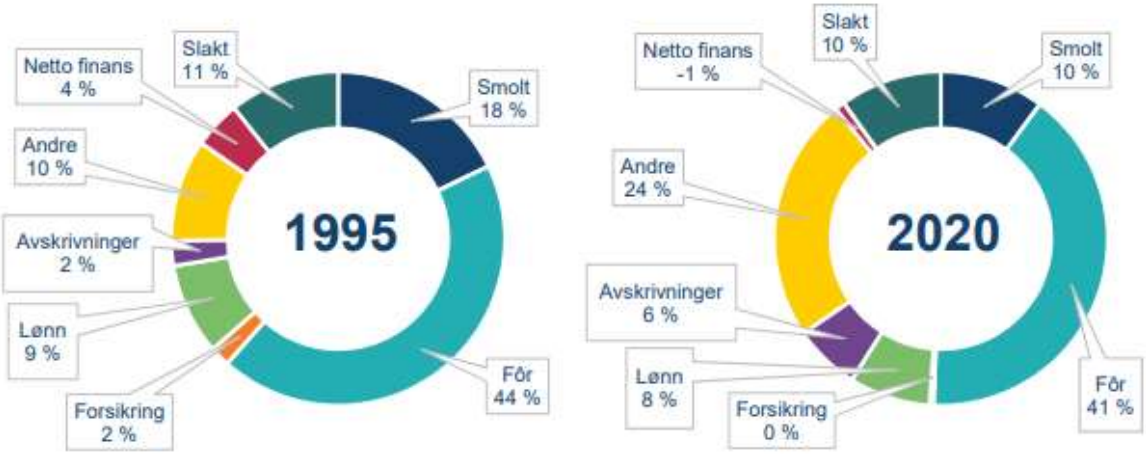

Figure 9: Percentage distribution of the various cost elements 1995 and 2020 (Fauske, 2021).

The picture above illustrates how the cost is distributed in 1995 and 2020. The picture indicates that most expenses is equal in size. We can see that the juvenile fish has become a less part of the cost, while other cost has increased. The other (Andre) column increases from 1995 to 2020 can be explained with higher transportation- and energy costs.

4.0 Data and Methods

My main method has been interviewing different stakeholders and involved parties. This has given me some constructive meetings and pointers to problems related to the transport chain in the seafood industry. Not surprisingly, the stakeholders who have the most to potentially earn by a renewal of the transport chain were easiest to get in touch with. Some businesses that are involved in the transport chain that potentially have something to lose, never answered my inquiries.

Some interviews gave insight that some operators might bend the rules a bit to minimize costs and/or maximize profits.

Since Norway is the world's leading fish farmer of salmon, much research, articles and information are in Norwegian.

4.1 Data

4.1.1 Transport cost

To be able to do some transport calculations I was able to investigate transport data from Vikenco. This data gave me an insight on transport costs to various locations. Transport cost is deemed as cooperate secret. The transport data used has been approved for publication by Vikenco.

4.1.2 Driving ban overview

In 2021 The Norwegian Public Roads Administration started to systematically record trucks that were given driving bans due to spillage. It's important to note that the records contain all driving bans due to spillage. Therefore, not all trucks do necessary transport seafood. However, the representant emphasized that in almost all cases the trucks were transporting seafood, without being able to confirm whether all were transporting seafood.

The data are collected from all of Norway. The organization do have five districts:

The Norwegian Public Roads Administration districts	Norwegian Counties
North District	Nordland, Troms og Finnmark
Central District	Møre og Romsdal, Trønderlag
West district	Rogaland, Vestland
South District	Agder, Vestfold og Telemark, Viken, Oslo
East District	Innlandet

Table 1: The Norwegian Public Roads Administration districts.

The data is collected weeks 16-22 and 23-35 2021 for all district. The data shows the number of trucks that were given driving bans. The total number of controlled vehicles is unknown.

	Northern district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
16-22	18	0	5	13	2	16	18
23-35	14	0	10	4	10	4	14
Sum	32 (100%)	0 (0%)	15 (47%)	17 (53%)	12 (38%)	20 (62%)	32
Totals	32		32		32		

	Central District:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
16-22	63	0	18	45	11	52	63
23-35	162	0	113	49	43	119	162
Sum	225 (100%)	0 (0%)	131 (58%)	94 (42%)	54 (24%)	171 (76%)	225
Totals	225		225		225		

	Western district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
16-22	21	0	6	15	4	17	21
23-35	39	0	13	26	4	35	39
Sum	60 (100%)	0 (0%)	19 (32%)	41 (68%)	8 (13%)	52 (87%)	60
Totals	60		60		60		

	Southern district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
16-22	4	0	0	4	0	4	4
23-35	7	0	1	6	0	7	7
Sum	11 (100%)	0 (0%)	1 (9%)	10 (91%)	0 (0%)	11 (100%)	11
Totals	11		11		11		

	Eastern district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
16-22	36	0	26	10	13	23	36
23-35	48	0	11	37	6	42	48
Sum	84 (100%)	0 (0%)	37 (44%)	47 (56%)	19 (23%)	65 (77%)	84
Totals	84		84		84		

Table 2: Driving bans per district.

The data shows that Central district has given out more driving bans than all other districts combined. The control frequency for each district is not specified, but there are several things that can explain this high number in comparison to the other districts. Many processing plants are in the central district, meaning a lot of trucks will drive through the district freshly loaded. E6, Norway's main road from central/northern Norway goes through the central district, meaning transport from northern district heading towards Oslo Airport or Europe may drive through the district as well.

The data table indicates that foreign carriers are handed out the most driving bans. However, it is considered normal in the industry to use foreign carriers, especially when transporting out of Norway. Foreign carriers should therefore not be considered as aggravated.

The Road Administration provided additional data for the central district:

	Central district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
40 - 52	54	0	23	31	12	42	54
Sum	54 (100%)	0 (0%)	23 (43%)	31 (57%)	12 (22%)	42 (78%)	54
Totals	54		54		54		

	Central district:						
Week	Domestic Sender	Foreign Sender	Domestic Receiver	Foreign Receiver	Domestic Carrier	Foreign Carrier	Total driving bans
1 - 7	41	0	10	31	6	35	41
Sum	41 (100%)	0 (0%)	10 (24%)	31 (76%)	6 (15%)	35 (85%)	41
Totals	41		41		41		

Table 3: Additional driving ban data for Central district.

If we look closer to the Central district, we have the following frequency of driving bans per day:

Weeks	No. driving bans	Driving bans per day
16-22 (2021)	63	1,29
23-35	162	1,78
40-52	54	0,59
1-7 (2022)	41	0,84

Table 4: Driving ban frequency for central district.

As earlier mentioned, the frequency of controls is not provided. We can still see a tendency that there are given out more driving bans in the summer months. The weeks 23-35 is the summer months June, July and August 2021. Here we can see that the frequency of driving bans per day is more than triple the frequency during October, November and December (weeks 40-52).

4.2 Methods

4.2.1 Economic analyze of impact of changing cooling refringent

According to Seafood Norway, Norway exported 1,04 million tons of fresh whole salmon (with head) in 2021 (Norwegian seafood council, 2022). This volume represents the total biomass exported. Whole salmon is widely sent with wet ice as cooling refringent because of indications of discoloration on gills. In many markets the color of the gills is a quality mark. If we calculate 4 kg of ice per 20 kg box, we can calculate the total transport weight as follow:

$$1{,}04\ mill\ tons * 1{,}2\ added\ ice = 1{,}248\ million\ tons\ transported$$

Equation 1: Fresh whole salmon + cooling refrigerant transported in 2021

This estimate applies if everything is transported with wet ice. A factor that is not included is the box weight. This is a fixed parameter whether wet ice or dry ice is used, therefore not included in this estimate. An EPS box weighs around 0,6 kg each.

To understand what economic impact this has we have to look at where the fresh whole salmon is transported to. Below is a limited selection of destinations for fresh whole salmon exports:

Export destination	Volume (in tons)	Avg. purchase price (NOK/kg)
Poland	178 925	53,42
Japan	13 735	63,05
USA	9 476	66,98

Table 5: Fresh whole salmon export and avg. purchase price (Norwegian Seafood Council, 2022).

The first observation is that countries further away is willing to pay a higher price than countries in Europe. For example, USA paid 25% more per kilo than Poland in 2021. This is not due to higher transport costs, since transport costs comes in addition. The willingness to pay is higher in high developed counties like USA and Japan. In addition to willingness to pay, countries like USA and Japan has a high demand of high-quality salmon. Quality and willingness to pay is the explanation of the price deficit between USA and Japan versus Poland.

To be able to calculate the economic impact of the added weigh wet ice represent, we need to find out what the expected transportation costs were in 2021 for the respective countries. In data provided by Vikenco, the average transport cost was as follow:

Export destination	Avg freight cost NOK/kg
Poland	0,96*
Japan	20,01**
USA	20,87

Table 6: Avg. Freight cost from Vikenco to selected countries.

* The transport cost to Poland is calculated as an average cost of one truck from central Norway to Poland. The cost is converted from Euro to NOK by the rate of 9,65 NOK/1 EUR. This cost does not include diesel add-on which is variable.

**The transport cost for Japan and USA includes both truck and air freight. Its common in intercontinental sales for fish exporters to use DPU Incoterms® 2020. In short terms, this means that exporters pay for transport to destination airport unloaded.

By doing some quick calculations, you can estimate the transport cost and added cost due to wet ice:

Export destination	Freight cost raw material	Freight cost ice (20%)
Poland	171 768 000 NOK	34 353 600 NOK
Japan	274 837 350 NOK	54 967 470 NOK
USA	197 764 120 NOK	39 552 824 NOK

Table 7: Calculated freight cost raw material and cooling refrigerant.

In 2021 it was exported 123 350 tons of fresh salmon fillets. It is estimated that the demand for fillets will increase, especially in high-cost countries. The increase in fresh fillet from

2020 to 2021 was 21,4%, according to Norwegian Seafood Council. Below is an overview of export of fresh salmon fillets in 2021:

Export destination	Volume (in tons)	Avg. purchase price (NOK/kg)
Poland	14 107	67,77
Japan	21 144	87,64
USA	25 643	106,61

Table 8: Fresh salmon fillet export and avg. purchase price (Norwegian Seafood Council, 2022).

The data above shows that high-cost countries like USA and Japan has a higher export volume for fresh fillets, due to the demand of high-quality salmon. The usage of dry ice has come the furthest when transporting fresh fillets. This is mainly due to air freight. USA and Japan are the two top export destinations for fresh salmon fillets. Still, the usage is not considered to be widespread in the industry.

According to the Norwegian Seafood Council the total export value of fresh salmon fillets in 2021 was 11,59 billion NOK (Norwegian seafood council, 2022). The average export price in 2021 was 93,92 NOK/kg. In comparison, fresh whole salmon had an export price of 58,71 NOK/kg.

Fresh fillets are packed differently than whole salmon. There may be different options in terms of volume per box. Vikenco has a 17 kg box as the most popular option. One 17 kg box will need approximately 1-2 kg of cooling refrigerant. When calculating the transport cost for fresh fillets, 10% is used as added weight due to wet ice.

Export Destination	Freight cost raw material	Freight cost ice (10%)
Poland	13 542 720 NOK	1 354 272 NOK
Japan	423 091 440 NOK	42 309 144 NOK
USA	535 169 410 NOK	53 516 941 NOK

Table 9: Calculated freight cost for raw material and cooling refrigerant.

It’s important to note that the exact weight of the cooling refrigerant is hard, if not impossible to find due to different practices and variance. Considering that some processing plants is using dry ice, the average added weight due to cooling refrigerant might be lower. Considering the total export volume of 123 350 tons fresh salmon fillets, there could be up to 12 335 tons of added wet ice being transported. This represents a large potential to reduce transport weight, thus transport cost and pollution in the transport chain. According to a report by SINTEF, the transport of one kg of edible product to Tokyo by air freight can pollute as much as 10 kg CO_2 equivalents (Hognes, 2014).

4.2.2 The climate footprint of the salmon industry

In 2015 the United Nations Sustainable Development Goals were established. In short terms, the Development Goals were created as a blueprint for peace and prosperity for people and the planet, now and into the future (United Nations, 2022). Among the 17 main goals is climate action. The goal state that comprehensive actions need to take place to stop the increase of greenhouse gas emissions by 2030. To achieve this goal, all countries, organizations and individuals need to do their part. The seafood industry position in Norway, as the second largest export sector, has a major responsibility. Export are synonymous with transport, and transport is synonymous with emissions. In the figure from Hognes` report "*Emissions from the Norwegian fish- and aquaculture industry – Where to do stand?"* 23,7% of emissions in the seafood industry comes from transport. The total emission from the seafood sector is estimated at 8,3 million tons CO2 equivalents in 2013. This is approximately 16% of the total pollution in Norway in 2013, which were 52,8 million tons. It is important to note that the pollution linked to the Norwegian seafood sector include pollution outside Norway, but that's part of the process. For example, production of fish feed and transport.

According to an e-mail from the Norwegian Environment Agency, the seafood industry accounts for only 0,4% of emissions subject to quotas in Norway. All the company represented on the list are producing herring meal, an ingredient in fish feed.

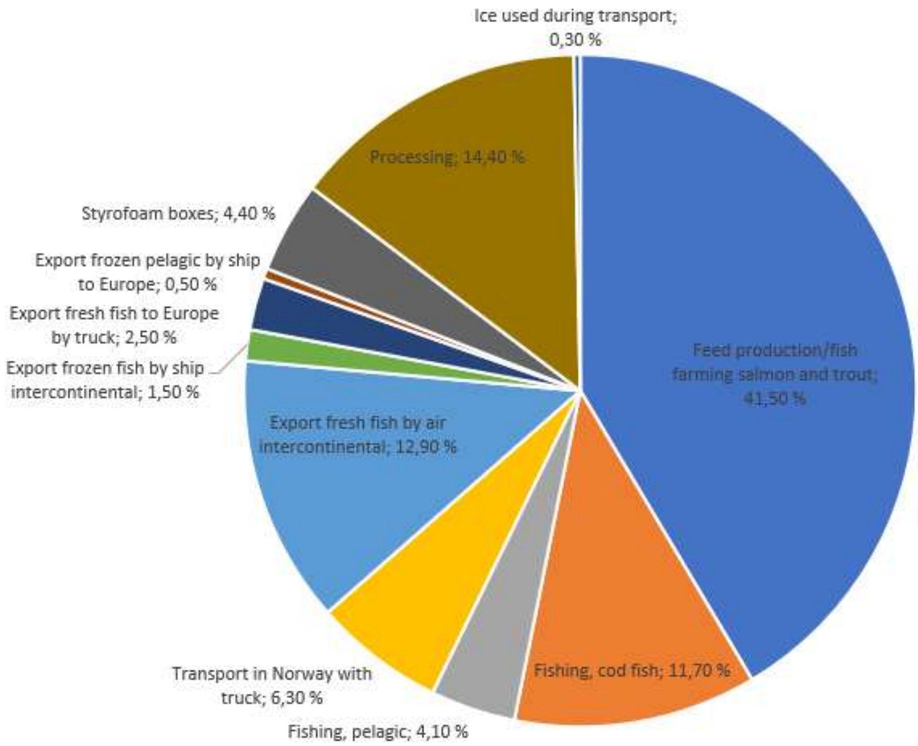

Figure 10: Pollution from the Norwegian seafood industry (Hognes, 2014).

A SINTEF report from 2020 has calculated the emission for several Norwegian seafood products. The report is thorough using data from earlier research and fish farmers. For example, it is estimated that service vessels use 0,015 liter of fuel per kg salmon produced. Some fish farms use generators to power electrical devices on the farm, lightning, feeding etc. It is estimated that the use of generators uses 0,04 liter of fuel per kg salmon produced (Winther, 2020). As figure 10 display, over 40% of the emission comes from the feed production.

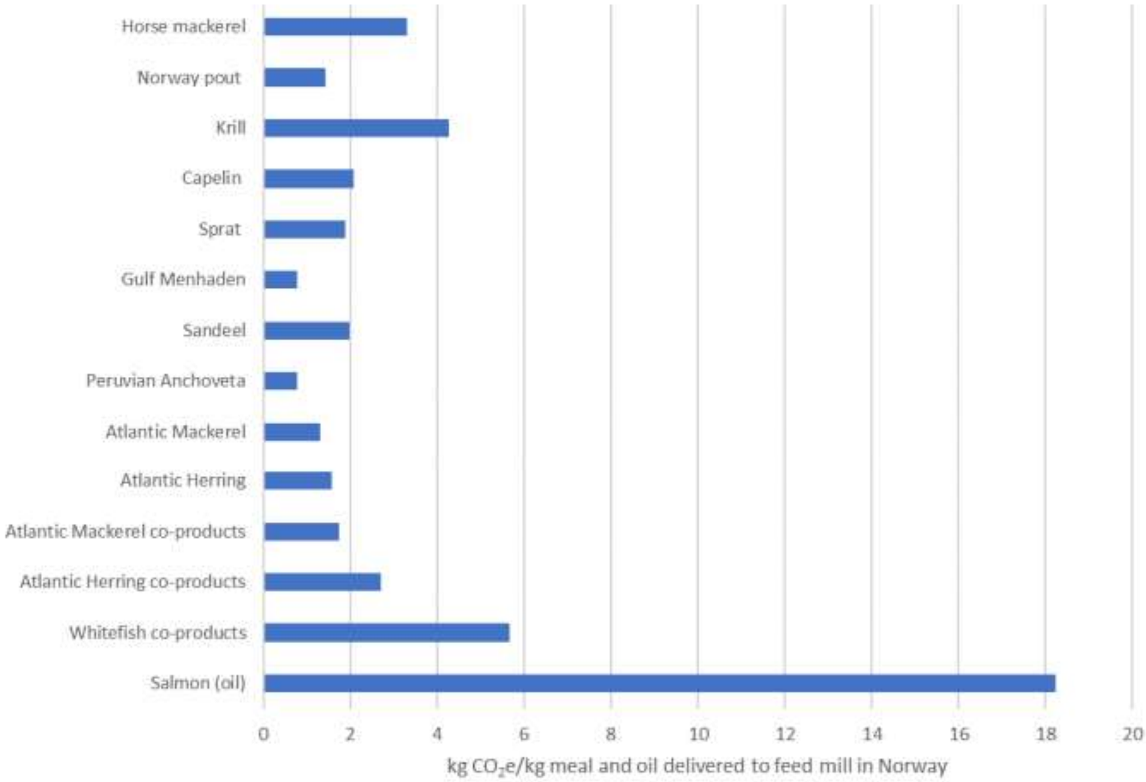

Figure 11: Greenhouse gas emissions of marine ingredients as delivered to feed mills in Norway (Winther, 2020).

In the 1990s salmon feed consisted of up to 90% fish oil and fishmeal. This was deemed both expensive and not sustainable with the rapid growth in salmon farming. Hence, the fish feed industry is now using up to more vegetable content. It is estimated that salmon feed contains of approximately 70% vegetable ingredients and 25% fishmeal/oil (Laksefakta, 2022). The vegetable ingredients to produce salmon feed is transported from all over the world to feed mills in Norway. According to the earlier mentioned SINTEF report, soy represents 20,6% of the feed. All soy is produced and transported from Brazil. Other ingredients are transported from Europe, except sunflower seed meal which is imported from Argentina and China.

4.2.3 Road freight

Road freight is essential to rapidly transport salmon to the customers. Due to the processing plants locations along the Norwegian coast, road freight is the only option to get the product outbound. Since the locations are spread out, it is difficult for other modes of transport to be competitive. Due to the geography of Norway, rail is inaccessible along most of the coast, and naval freight takes too long time. This leaves the industry with road freight to get the product directly to the customer, or to major air freight hubs where it is flown to desired destination.

The road freight segment is highly competitive, and exporters tend to choose carriers based primarily on price and availability. Major East-European carriers such as Girteka and Kreiss is often used on transport out of Norway. According to an article from 2021, Girteka is portrayed as one of the market leaders in salmon transport, having approximately 7800 trucks in its fleet (Nodland, 2021).

SINTEFs report “Greenhouse gas emissions of Norwegian seafood products in 2017” has a detailed overview of emissions related to road freight. The trucks used to transport seafood is categorized as Heavy Duty Vehicles (HDV). The vehicles are limited by EU law on how much payload they can take. It depends on the type of vehicle. A three-axle vehicle is limited to 25 tons, or 26 tons if the driving axle is fitted with twin tyres and air suspension or suspension recognized as being equivalent within the Union (EU, 2015). This is also the vehicle that SINTEF has used in its example.

Vehicle utilization is a calculated factor to determine how well utilized a vehicle is used. In cargo transport utilization can be calculated with respect to weight or volume. SINTEF has made the following overview of utilization for HDV:

		Product/value	
Parameter	**Unit**	**Fresh**	**Frozen**
Fish per truck	kg	18,500	22,000[16]
Weight per box	kg	0.60	2.00
Fish per box	kg	20	25
Ice per box	kg	5	0
Euro pallets per vehicle	pieces	33	33
Weight/Euro pallet	kg	25	25
Total payload. Fish + ice + packaging	ton	24.50	25.03

Figure 12: Data used to calculate utilization of load capacity on trucks for transportation of fresh and frozen fish (Winther, 2020).

The mark “16” is information stating that Norwegian fish exporter Lerøy has informed SINTEF that they do send as much as 23 ton of frozen fish per truck (Winther, 2020).

HDV is limited by volume to 33 euro pallets. When calculating the ice needed for a full truck, the example shows that fresh seafood needs approximately 4,6 tons of ice to maintain quality during transport. This means that it is possible to send more frozen seafood due to no excessive ice weight.

If all trucks that are being sent is fully loaded, the utilization factor is 1. The best way of calculation the utilization factor on the return trip is to use the average European utilization factor for HDV, 0.64. The average load factor is as follow:

$$Avg.utilization = \frac{utilization\ export + utilization\ return}{2} = \frac{1 + 0.64}{2} = 0.82$$

Equation 2: Utilization factor for salmon trucks, export and return.

Considering a fuel use of 0.4 liter/km, the fuel use can be calculated as follow:

$$Avg.fuel\ use\ HDV\ truks = fuel\ use\ /\ cargo\ weight\ /\ utilization\ factor$$

The calculations are shown in figure 12.

Parameter	Unit	Value
Fuel use HDV trucks	l/km	0.40
Max payload (by EU regulations)	ton	25
Average European utilization factor for HDV (PEF guide [23])	actual payload/max payload	0.64
Average utilization factor export	actual payload/max payload	1
Average load utilization factor, export and return	actual payload/max payload	0.82 (0.64+1)/2 = 0.82
Fuel use HDV trucks, average export and return	L fuel/ton*km	0.020 0.4/25/0.82 = 0.020

Figure 13: Key parameters used in the modelling of truck transportation of seafood (based on personal communication with fish exporting companies and the road transport operators) (Winther, 2020).

To find out how much the added ice pollutes, some popular destinations are selected as examples. London Heathrow Airport, Paris and Szczecin. In this example, Trondheim is the departure city.

Destination	Total distance	Ferry distance	Road distance
London Heathrow Airport	2 253 km	204 km	2 049 km
Paris	2 191 km	163 km	2 028 km
Szczecin	1 471 km	113 km	1 358 km

Table 10: Distance to selected destinations from Trondheim. Source: Google Maps.

Fuel use is calculated as follow:

$$Fuel\ use = (L\ Fuel/ton * km) * \ payload\ weight * distance\ in\ km$$

Equation 3: Fuel use per salmon truck

In this example diesel is the fuel used. Diesel weighs 835 grammes. Diesel consist of 86,2% of carbon, or 720 grammes of carbon per liter diesel. In order to combust this carbon to CO2, 1920 grammes of oxygen is needed. The sum is then 720 + 1920 = 2640 grammes of CO2/liter diesel (Ecoscore, 2022).

Destination	Fuel use ice (4,6 tons)	CO2
London Heathrow Airport	188.50 L	497.64 kg
Paris	186.58 L	492.57 kg
Szczecin	124.94 L	329.84 kg

Table 11: Calculated average fuel use and CO2 emission for the transported ice from Trondheim to selected destinations.

4.2.4 Air freight

To be able to serve the high-cost markets such as USA, Japan and South Korea, the only possible mode of transport to get the product to its destination fresh is air freight. Air freight is the most expensive mode of transport and is mainly used for high-value goods. One of the biggest challenges for air freight is the emissions. It is widely used as an argument among shipping carriers arguing that shipping is much more environmentally friendly. When calculating CO2 emissions per tonne-kilometre air freight is by far the worst.

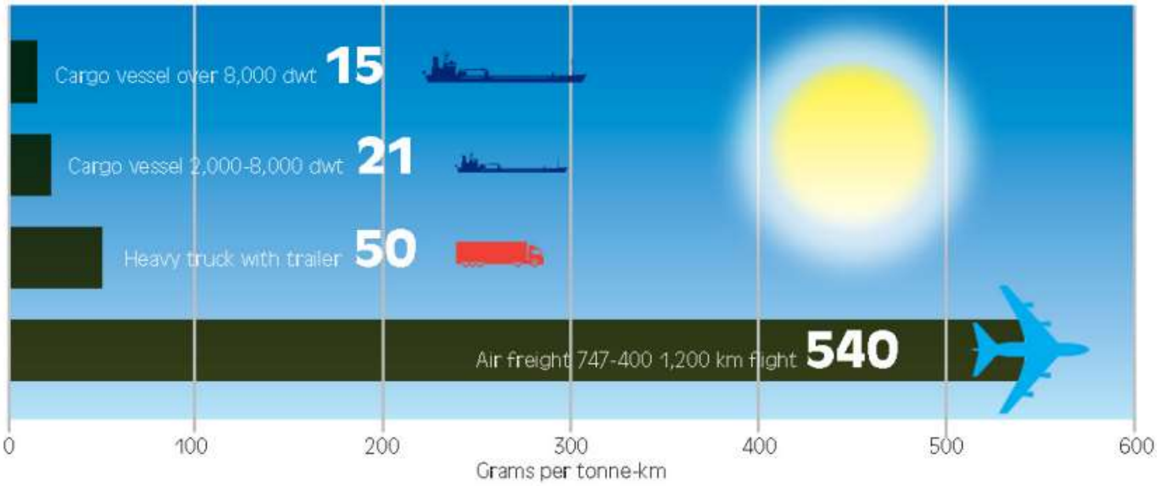

Figure 14: CO2 emissions comparison (Vermeire, 2013).

On short-term there are no substitute transport for fresh seafood. Shipping takes too long, and rail are to complex, or do not simply exist due to the Atlantic or the great distance to the Far East. To minimize the emissions from the seafood industry, it is vital to shed of additional weight.

By using a simple carbon emission calculator online, it was possible to get a grasp on how air freight stack towards other transport methods. In the example below Trondheim, Norway is selected as departure for pre-carriage. The pre-carriage distance is 2357,64 km to Heathrow airport London by truck. The Main carriage is air freight, Heathrow Airport to JFK Airport, New York. The selected transport weight is set to 4000 kg, as this is approximately what one air freight container (PMC) with fresh salmon weighs.

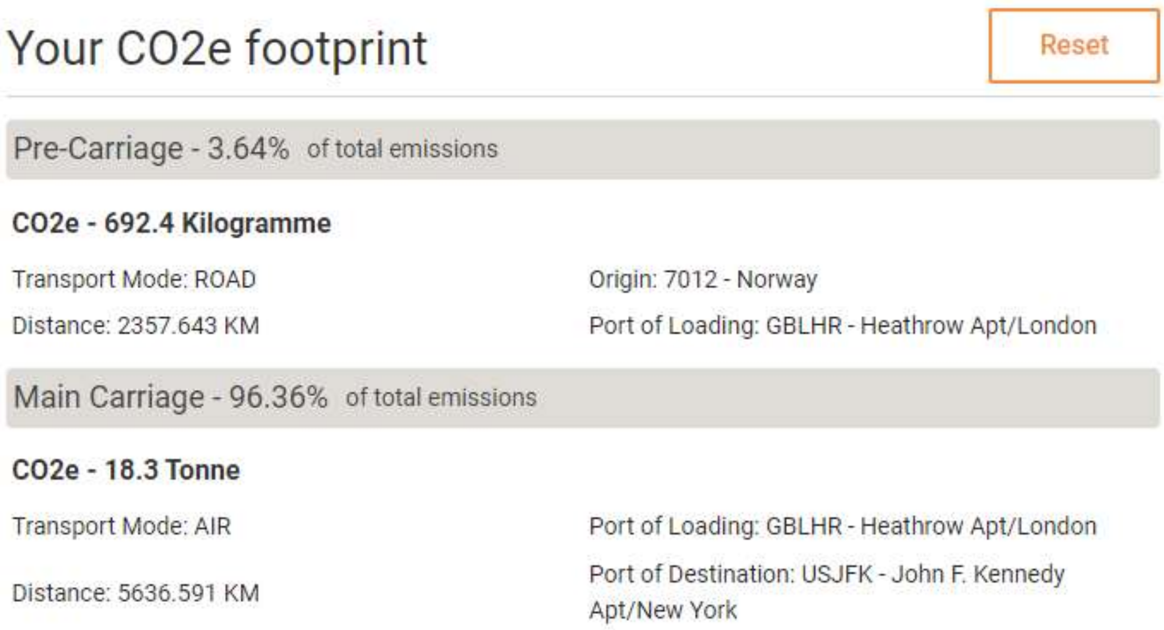

Figure 15: Pollution calculator (Logward, 2022).

The calculator used in this example is a simple version. The results should therefore only be an estimate, not real emission figures.

The results from the example illustrates the high pollution connected to air freight. The pre-carriage road transport is approximately 29,5% of the total transport distance, but only 3,64% of the total emissions. Post-carriage is not calculated in this example since its common for importers to be in charge for that leg.

The Network for Transport Measures (NTM) is a non-profit organization, initiated in 1993 aiming at establishing a common base of values on how to calculate the environmental performance for all various modes of traffic, including goods transport and passenger travel (Network for Transport Measures, 2022). NTM has made a baseline that can be used to calculate emissions. Their 2021 air cargo baseline can be seen in figure x.

2021				Radiative forcing index			
				1	1	1	1
				ttw		wtw	
NTM data	Distance ranges [km]	Calculation distance [km	Use weight [%]*	CO_2 Fossil [kg/tkm	Energy [MJ/tkm]	CO_2e [kg/tkm	Energy [MJ/tkm]
Regional freight aircraft	<785	463	100%	1,82	25,5	2,1	29,3
Continental freight aircraft	785-3600	1108	70%	0,82	11,5	0,92	13,2
Intercontinental freight aircraft	>3600	6482	70%	0,52	7,3	0,58	8,4
Continental belly aircraft	785-3600	1108	30%	0,97	13,5	1,1	15,6
Intercontinental belly aircraft	>3600	6482	30%	1,0	13,9	1,1	16,0
Average regional air freight transport	<785	463		1,82	25,52	2,10	29,34
Average continental air freight transport	785-3600	1108		0,87	12,12	0,97	13,93
Average intercontinental air freight transport	>3600	6482		0,66	9,29	0,74	10,68
* Used to assess average freight aircraft based on traffic data							
State of the art intercontinental belly aircraft **	>3600	6482		0,65	9,16	0,73	10,53
** Present best aircraft in belly operation							

Figure 16: Air cargo transport baseline (NTM, 2022).

The baseline calculates CO2 emission in kg per tonne-kilometer transported. There are two categories, well to wheel (wtw) and tank to wheel (ttw). Tank-to-wheel is the subrange in energy chain of a vehicle that extends from the point at which energy is absorbed to discharge. Well-to-wheel describes the subrange of fuel supply from production of the energy source to fuel supply (Volkswagen AG, 2022). In addition, the term well-to-tank (wtt) is the process of energy production. The connection between these abbreviations is as follow:

$$WTT + TTW = WTW$$

Equation 4: Well-to-Wheel definition

In the example in table x one air freight pallet (PMC) is transported by passenger aircraft from London to common destinations for fresh salmon, New York, Los Angeles and Tokyo. In the example the weight of the PMC is set to 4 tons. The following equation is used to calculate the emission of sending one PMC:

$$Emission\ per\ PMC = Weight\ in\ tons * Distance\ in\ km * CO2e\ wtw\ factor$$

Equation 5: Emission in CO2e for sending 1 PMC.

To visualize the difference between new more fuel-efficient aircraft and older ones, both the baseline for intercontinental belly aircraft and state of the art belly aircraft is calculated.

Destination	Distance in km	Intercontinental belly aircraft, pollution in CO2e	State of the art intercontinental belly aircraft, pollution in CO2e
New York	5570	24,5 tons	16,3 tons
Los Angeles	8756	38,5 tons	25,6 tons
Tokyo	9559	42,1 tons	27,9 tons

Table 12: Estimated emission transporting one air freight pallet (PMC).

Destination	Distance in km	Intercontinental belly aircraft, CO2e/km	State of the art intercontinental belly aircraft, CO2e/km
New York	5570	4,4 kg	2,93 kg
Los Angeles	8756		
Tokyo	9559		

Table 13: Emission for transporting one air freight pallet per kilometer.

The results should be considered an estimation, not actual emission. There are several factors that can impact the actual emission.

Belly aircraft are referring to the belly cargo room in passenger planes. The NTM baseline is an average. An important variable to accurately calculate emission allocated to a specific shipment is the utilization. The variation can be great due to seasonal changes in passenger traffic. The results do underline the high carbon footprint fresh salmon has when transported overseas. The results also show the importance for airlines to continuously renew their fleet to be able to fly fuel-efficient.

In a report from 2021 ordered by Avinor (Operator of Norwegian airport and civilian air traffic), “Transportutvikling AS” investigated air freight of fresh seafood from northern Norway. In the report both passenger and freight aircraft were discussed as a possibility.

There have been attempts to have a “salmon-route” with freight aircraft from northern Norway to Asia. During the corona pandemic Qatar Airways opened a freight route from Bodø Airport to Doha, Qatar. Virgin Atlantic Cargo also operated a route from Evenes to London. During the early stage of the pandemic the number of intercontinental passenger flights decreased due to lockdowns. The supply of cargo space decreased, and air freight rates flew through the roof. In addition, many planes were put on the ground due to thin base to fly. This opened the opportunity to use planes that otherwise was stationary to be used to transport salmon. Already late in 2021 when international air traffic picked up again, the number of “salmon-flights” from northern Norway decreased.

4.2.5 Carbon footprint Comparison

The "Greenhouse gas emission of Norwegian seafood products in 2017" has mapped the greenhouse emission of 21 Norwegian seafood products in 2017. The product spans from red fish, white fish to shellfish. In addition, different modes of transport are compered.

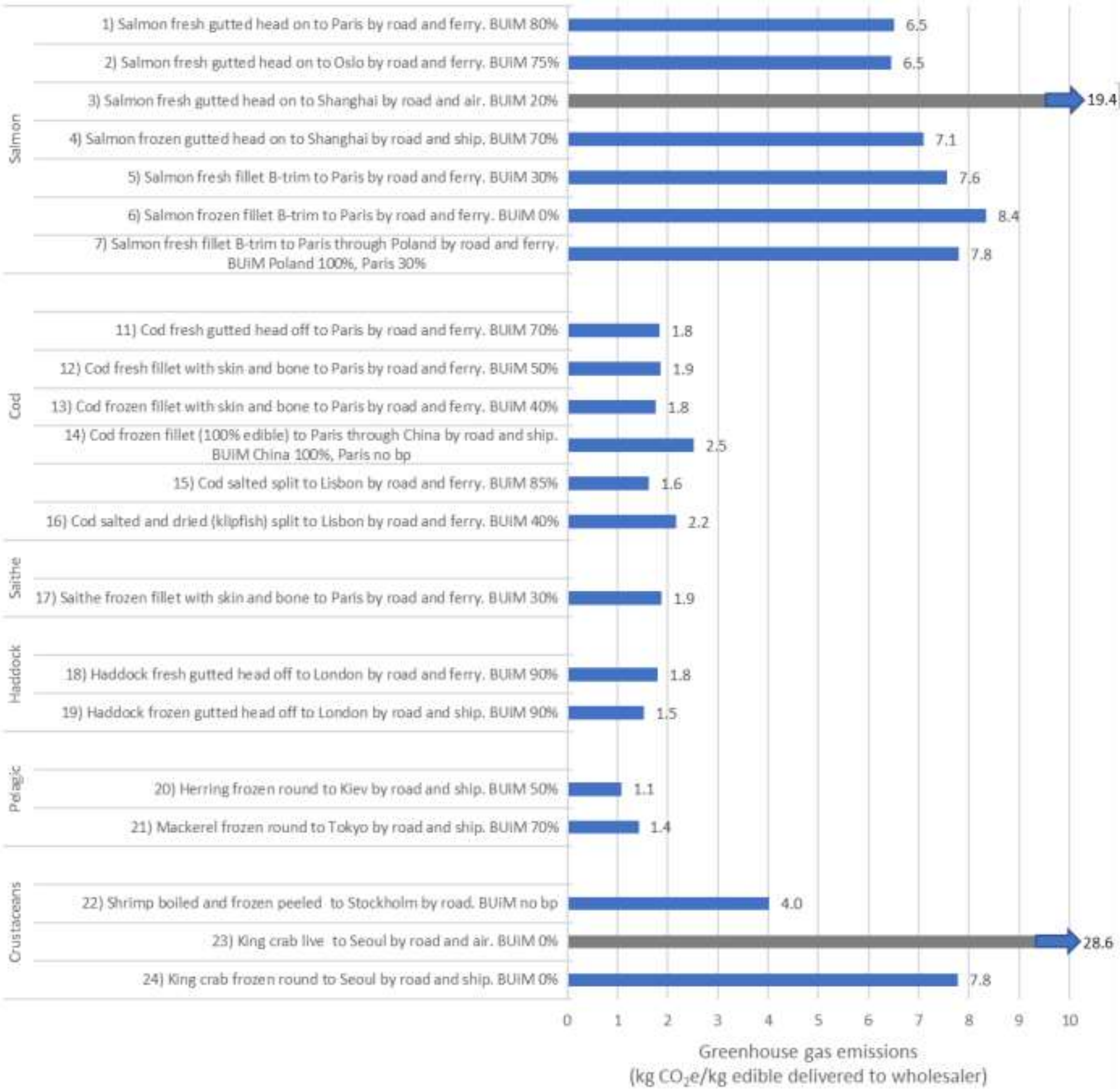

Figure 17: Greenhouse gas emissions from all studied products delivered to wholesaler. BUiM = by-product use in market (Winther, 2020).

The results do underline that salmon and king crab have the largest carbon footprint. As the results show, the destination does affect the results to great extent.

When comparing salmon to other high protein food option, the salmon does not come out as bad.

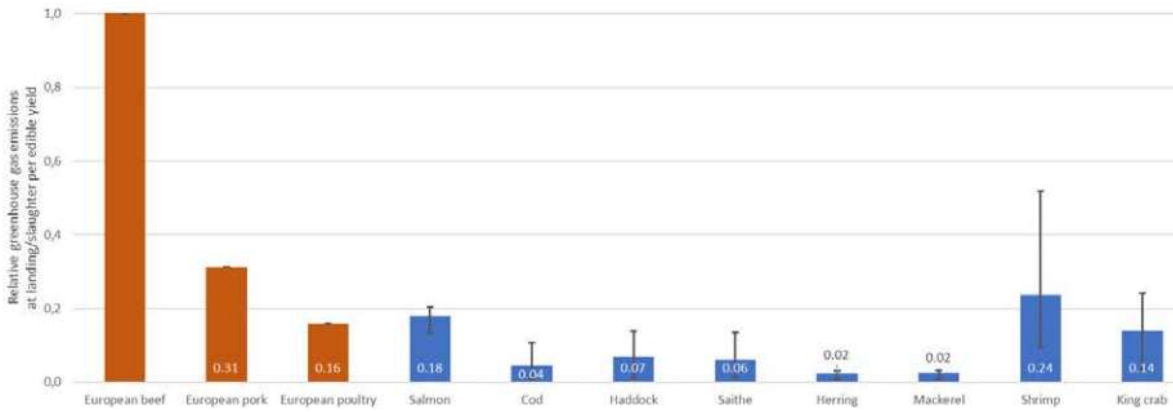

Figure 18:Relative greenhouse gas emissions of seafood (blue bars) at landing/slaughter vs. European terrestrial animal-source foods (brown bars), with average values in relation to European beef. Error bars for seafood represent min and max values under current production practice. Similar estimates for min/max or variability are not available for the terrestrial animal foods in the data used.

To be able to feed the world’s population, it is necessary to produce food sustainable. Compered to red meat, salmon is considered a more sustainable option. According to a documentary about the Norwegian salmon industry aired on NRK in 2020, “Folkeopplysningen”, Norwegian farmed salmon exported by air to china pollutes less per kg edible than local produced beef (Wahl, 2020). This is a key argument for the Norwegian seafood industry in the sustainability debate.

Another sustainable aspect is the use of water to produce food. According to an overview made by Norwegian environmental organization “Framtiden i våre hender” it is needed 15 415 liters of water to produce 1 kg beef. Norwegian farmed salmon needs 0 liter, although water is needed during the slaughter process to clean the product and to produce water ice. Either way, the water usage is way less than other high protein food options. Other examples are pork that need 5988 liter of water per kg edible product, and eggs that need 3265 liter per kg edible product (Lindahl, 2022).

5.0 Findings

5.1 Potential Overweight

In the meeting with Nippon Gases, it was claimed that some trucks with wet ice as cooling refringent, deliberately are sent off from processing plants overweight, knowing that enough spillage will be spilled before they reach the known control stations. If true, it is a serious offence that increases risk of dangerous situations. This is however difficult to find out, since the industry and transporters would never confirm this practice.

The EU has regulations to ensure the food hygiene in Europe. According to this regulation "during transport, fishery products must be maintained at the required temperature. In particular: fresh fishery products, thawed unprocessed fishery products, and cooked and chilled products from crustaceans and molluses, must be maintained at a temperature approaching that of melting ice" (Reg. 853/2004, Annex III, section VIII, chapter VIII-1a). "If fishery products are kept under ice, melt water must not remain in contact with the products" (Reg. 853/2004, Annex III, section VIII, chapter VIII-3). If the claim is true, carriers are violating the EU regulations to ensure food hygiene in Europe.

The claim was forwarded to The Norwegian Public Roads Administration. They stated that they have no information or indication that salmon transports are purposely driving overweight.

5.2 Economic impact of using wet ice as cooling refrigerant for fresh whole salmon

Considering the Norwegian Seafood Council numbers, Norway exported 1,04 million tons of fresh whole salmon in 2021. By doing some simple calculations we can calculate how much wet ice that is transported with fresh whole salmon, when 20% is considered:

$$1{,}04 \; million \; tons \; raw \; material * 0{,}2 = 208\;080 \; tons \; of \; cooling \; refrigerant$$

Equation 6: Volume of cooling refrigerant transported in 2021.

Of this volume, 906 251 tons of raw material were exported to EU members plus the Great Britain. 110 029 tons were exported outside Europe.

Given that all export to EU + Great Britain were transported by truck, the freight cost only includes road freight. Off the 906 251 tons of raw material exported, an estimated 181 250 tons of wet ice was transported as well. It is very difficult to find an accurate transport cost for all destinations. In addition, transport distance can variate a lot, depending on where each trucks destination is. To simply the equation, all destinations within EU + Great Britain who have imported more than 1000 tons is included. Distance is calculated from Trondheim to all country's capitals. The road freight cost is set to an average of 1 NOK/kg per 1500 km of road distance, we have the following results:

Country	Volume in tons	Ice Volume in tons	Total weight transported in tons	Road distance to capital from Trondheim in km	Road freight cost		Total cost	
Poland	178 925	35 785	214 710	1 902	kr	1,27	kr	272 252 280,00
Denmark	111 859	22 372	134 231	1 092	kr	0,73	kr	97 720 022,40
France	101 876	20 375	122 251	2 028	kr	1,35	kr	165 283 622,40
Netherlands	88 539	17 708	106 247	1 593	kr	1,06	kr	112 834 101,60
Spain	79 894	15 979	95 873	3 293	kr	2,20	kr	210 472 753,60
Italy	65 713	13 143	78 856	2 801	kr	1,87	kr	147 249 690,40
Great Britain	58 488	11 698	70 186	2 020	kr	1,35	kr	94 516 608,00
Germany	36 454	7 291	43 745	1 418	kr	0,95	kr	41 353 417,60
Lithuania	38 401	7 680	46 081	1 275	kr	0,85	kr	39 169 020,00
Finland	26 063	5 213	31 276	1 057	kr	0,70	kr	22 038 872,80
Sweden	18 805	3 761	22 566	776	kr	0,52	kr	11 674 144,00
Portugal	11 091	2 218	13 309	3 754	kr	2,50	kr	33 308 491,20
Czech Republic	7 658	1 532	9 190	1 765	kr	1,18	kr	10 813 096,00
Turkey	5 472	1 094	6 566	3 604	kr	2,40	kr	15 776 870,40
Ireland	5 068	1 014	6 082	2 513	kr	1,68	kr	10 188 707,20
Belgium	4 400	880	5 280	1 771	kr	1,18	kr	6 233 920,00
Greece	4 265	853	5 118	3 850	kr	2,57	kr	13 136 200,00
Estonia	4 130	826	4 956	1 060	kr	0,71	kr	3 502 240,00
Latvia	2 932	586	3 518	1 022	kr	0,68	kr	2 397 203,20
Romania	1 728	346	2 074	3 114	kr	2,08	kr	4 304 793,60
Sum	851 761	170 352	1 022 113				kr	1 314 226 054,40

Figure 19: Estimated transport cost for fresh whole salmon to EU + Great Britain in 2021.

When taking the results into account, the total transportation cost to EU countries + Great Britain is 1,31 billion NOK in 2021. If wet ice represents 20% of the weight, the cost to transport the ice is 262,8 million NOK in 2021.

For overseas markets the top five importers is selected. Freight cost include both road- and air freight. The freight cost used is provided by Vikenco. The same freight cost is used for the Far East destinations. This is to simplify the calculation.

Country	Volume in tons	Ice Volume in tons	Total weight transported in tons	Freight Cost/kg	Total cost
South Korea	29 668	5 934	35 602	kr 20,01	kr 712 388 016,00
China	25 676	5 135	30 811	kr 20,01	kr 616 532 112,00
Taiwan	15 076	3 015	18 091	kr 20,01	kr 362 004 912,00
Japan	13 735	2 747	16 482	kr 20,01	kr 329 804 820,00
USA	9 476	1 895	11 371	kr 20,87	kr 237 316 944,00
Sum	93 631	18 726	112 357		kr 2 258 046 804,00

Figure 20: Estimated transport cost for fresh whole salmon to selected overseas markets in 2021.

The transport cost to the selected destinations is 2,258 billion NOK in 2021. This illustrates the willingness to pay in certain overseas markets. The estimated cost of transporting the cooling refrigerant is 451,6 million NOK in 2021.

The 20% added weight of using wet ice as cooling refrigerant for whole salmon may cost exporters 700-800 million NOK annually. Considering the increased transport prices in 2022 due to inflation and fuel prices, the number might be even higher.

5.3 Climate footprint in the transport chain

It is not easy to map the exact emission related to the transport chain. Processing plants are located along the long Norwegian coastline. Trucks might have different option when driving towards the markets, and air freight may have different departure airport for the same arrival airport.

To scope this, five countries is selected. Poland and France as they are the largest- and third largest importers of fresh whole salmon in Europe respectively. South Korea and China are the two largest importers in the Far East. The fifth nation is USA. This way, two countries that only need road freight is represented, and three countries that need both road- and air freight is represented.

Destination	Raw materials Volume in tons	Cooling refrigerant weight (20%) in tons	Total weight in tons	No. Trucks needed (25 ton payload)
Poland	178 925	35 785,0	214 710,0	8 588,4
France	101 876	20 375,2	122 251,2	4 890,0
South Korea	29 668	5 933,6	35 601,6	1 424,1
China	25 676	5 135,2	30 811,2	1 232,4
USA	9 476	1 895,2	11 371,2	454,8
Sum	345 621	69 124,2	414 745,2	16 589,8

Figure 21: Volume transported to selected destinations in 2021.

Figure 21 displays the estimated total weight transported to the destination countries. In addition, the number of trucks needed to transport the volume is calculated, each truck with 25-ton payload. To be able to calculate the emission related to the transport, road- and air distance is needed. Road distance is calculated with Google Maps, and air distance is calculated the straight-line air distance between departure airport and arrival city. For transport to the Far East, Helsinki Airport is used as departure airport. For transport to the USA, London Heathrow Airport is used as departure airport. To simplify destination, all countries destination city is their capital, except USA, were New York is selected.

To calculate the total road emission, equation 4 from chapter 4.2.3 is used, with one additional step:

$$Fuel\ use = (L\ Fuel/ton * km) * \ payload\ weight * distance\ in\ km * No.trucks$$

Equation 7: Fuel use for all trucks.

Equation 6 will provide the number of liters of diesel all the trucks need to transport the total volume. Last step is to calculate from fuel use to emission:

$$Road\ freight\ emission = Fuel\ use * CO2\ factor$$

Equation 8: Total road freight emission.

In chapter 4.2.3 we calculated that 1 liter of diesel combusts into 2,64 kg of CO2.

For air freight, the number of PMCs needed to transport the total volume is calculated. 1 PMC takes 4 tons. To calculate the emission related to the air freight, equation 5 from chapter 4.2.4 is used, with the number of PMCs needed as the extra step:

$$Total\ emission = Weight\ in\ tons * Distance\ in\ km * CO2e\ wtw\ factor * No.PMCs$$

Equation 9: Total air freight emission for 2021

Using these equations creates the following estimates:

Destination	Road distance in km	No. Trucks needed (25 ton payload)	Road freight emission in CO2e	Estimated air distance in km	No. PMCs needed	Air freight emission in CO2e	Total transport emission in CO2e
Poland	1 902,00	8 588,40	21 562 380,58				21 562 380,58
France	2 028,00	4 890,05	13 090 462,89				13 090 462,89
South Korea	1 057,00	1 424,06	1 986 911,06	7 058,00	7 417,00	230 336 418,40	232 323 329,46
China	1 057,00	1 232,45	1 719 560,75	6 319,00	6 419,00	178 471 308,40	180 190 869,15
USA	2 357,00	454,85	1 415 141,29	5 570,00	2 369,00	58 059 452,00	59 474 593,29

Figure 22: Calculated total emissions in the transport chain for 2021.

Given the estimates in figure 22, emission per kg whole salmon is as follow:

Destination	Volume raw materials in tons	Total emission in CO2e in kg	Emission per kg whole salmon transported
Poland	178 925	21,56 million	0,12 kg
France	101 876	13,09 million	0,13 kg
South Korea	29 668	232,32 million	7,83 kg
China	25 676	180,19 million	7,02 kg
USA	9 476	59,47 million	6,28 kg

Figure 23: Emission per kg whole salmon transported.

If 20% of the total weight is reduced, the potential results are as follows:

Destination	Total Emission in CO2e in kg	Emission per kg whole salmon transported
Poland	17,25 million	0,10 kg
France	10,47 million	0,10 kg
South Korea	185,86 million	6,27 kg
China	144,15 million	5,61 kg
USA	47,58 million	5,02 kg

Figure 24: Emission per kg whole salmon transported with 20% weight reduction.

6.0 Discussion

6.1 Future of the salmon industry

In chapter 2.3 the Norwegian Minister of Transport stated that they will consider tightening the regulations to stop spillage. As a response CEO of Norwegian Truck owners` Association (NLF) stated that he wishes changes welcome. In December 2020, NLF made an industry standard with the seafood industry that were meant to fix the problem. Within this standard are presupposed measures from the authorities. Among the suggestions is electronic and mandatory consignment note, a cabotage register, requirements for temperature logs, notification of transport buyers and a ban on too many links in the transport chain (Nodland, 2022).

Entirely clogged boxes are not mandatory for the seafood industry. The CEO of NLF thinks it is not used because of the higher price. The CEO also state that it is a shared responsibility between the seafood industry and the transporters to eliminate the spillage. The same article states that one truck with seafood may spillage as much as 1800 to 3600 liters during transport to Europe (Nodland, 2022).

Clogged boxes will prevent spillage but will also make carriers transport the melting water to its destination. The added cost of using clogged boxes can be saved by reducing the transport weight.

There are several ways for the salmon industry to move towards in the future. Traditional fish farming might change, as new solutions are being built, tested and implemented at this moment.

6.1.1 Land based salmon farms closer to the demand

In recent years there have been planned multiple land-based salmon farms in Norway. One of the main reasons is that it has become more difficult to receive new salmon licenses. This is due to several factors.

- Norway already has a lot of fish farms, which means that the best locations may already be in use.
- To high density of fish farms can restrict public- and private shipping.
- Fish farms has a contaminating effect towards the seabed.

The idea of land-based fish farms is not new. Juvenile fish has been farmed on land for decades in freshwater tanks. The strong demand and high prices for fresh salmon might also be a key element in the increase of land-based projects. The idea is to be able to farm the fish as close as possible to the demand. This will eliminate the need of intercontinental transportation. Isolated tanks will also eliminate escape and illness such as salmon louse. Some examples of land-based salmon farms:

- Atlantic Sapphire ASA that has operational facilities in Florida and Denmark
- Proximar AS are building a land-based farm in Japan that aims to serve the Tokyo market
- Salmon Evolution AS started operations in March 2022 in their new facility at Indre Harøy, Norway. They do also have entered partnership with South Korean Dongwon Industries, which include the plan of making a plant in South Korea based on the one made in Norway.

There are two mainly two different technologies that land-based salmon farms use. It is recycling system (RAS) and flow-through system. It is also possible to combine the two technologies. Salmon Evolutions farm in Indre Harøy is an example of a hybrid solution. The RAS technology is based on recycling the used water. The idea is that the reduced need for water makes it possible to locate the farm inland, potentially close to major logistics hubs, markets and labor. The downside is high power consumption. The high electricity consumption is one of the reasons why the production cost is much higher for land-based farms. The hope is that the savings in transportation will finance the added power cost. There have been some incidents of mass mortality in RAS-facilities. These have made some question if RAS is the right technology. In an article in July 2021 a "incident" led to 400 tons of salmon to die. According to Atlantic Sapphire this was due to human error during maintenance, that made the filter system malfunction (Furuset, 2021). In the same article earlier incidents is mentioned. In March 2021 around 500 tons died at their farm in Florida. The company blamed a "design error". There have been more incidents as well with various explanations.

The main weakness in a RAS system may be the vulnerability to technological malfunction. If malfunction were to occur, it can be difficult to access enough fresh seawater to sustain a livable environment for the salmon.

Andfjord Salmon AS is a publicly traded company based in northern Norway. They are investing on a flow-through facility at Andøya, Norway. Their patented land-based concept is planned to be sustainable, minimizing power consumption and production cost (Andfjord Salmon, 2022).

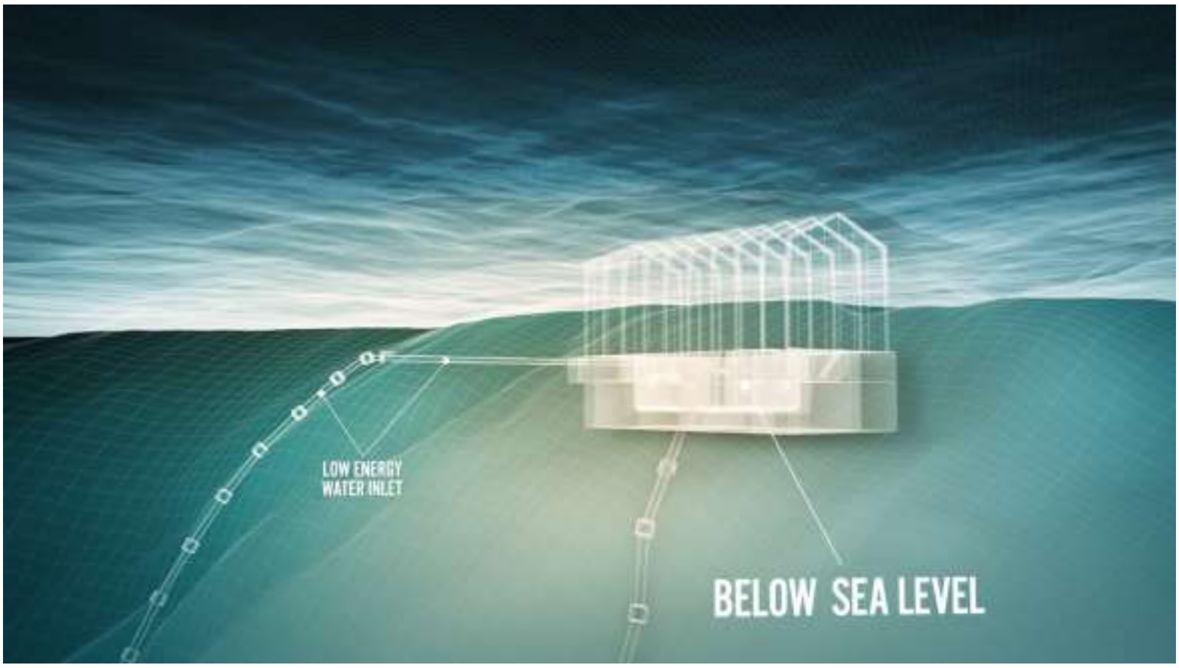

Figure 25: Illustration of the pools under sea level and water supply (Andfjord Salmon, 2022).

The flow-through system is not entirely isolated due to the water intake, but the idea is to pump in water from a depth where salmon louse and poisonous algae's do not sustain.

Andfjord Salmon also plan to deliver all bio-residues to a neighboring company that produces peat moss as a gardening supplement. According to Andfjord Salmon will this biproduct enhance the peat moss due to the increase in natural nitrate, phosphate and other nutrient salts (Andfjord Salmon, 2022).

6.1.2 Semi-closed cages

The idea of semi-closed cages is basically the sea version of land-based cages. The idea is to isolate the salmon in floating cages to protect the fish. Semi-closed cages can potentially replace open cages at fish farms.

The arguments for semi-closed cages are to improve fish health, quality control and waste control. Sea water is pumped into the cages from such a depth that lice and poisonous algae won't be a problem. The cages will also protect the wildlife in the sea around the fish farms. Feed and feces can be collected and used as fertilizer.

Figure 26: Example of semi-closed cage (FiiZK, 2022).

A semi-closed cage is more expensive to acquire than traditional cages. In 2021 the Norwegian government released a statement stating that they will impose regulations to protect wild salmon and to investigate legislation that will lead towards zero-emission production from 2030 (Bøhren, 2021). Among the potential measures is to make semi-closed cages mandatory. According to an article from September 2021, each semi-closed cage cost around 30 million NOK. If all salmon farms were to invest in new cages, the total investment cost would be 131 billion NOK (Knudsen, 2021).

Semi-closed cages will not impact the transport chain. It can however affect the climate footprint from the industry. Better quality control can decrease fish mortality and eliminate the need of cleaning fish.

6.1.3 Ocean cages

Ocean cages is a new project that aim to farm fish offshore. Ocean farming is a new concept being tested by Norwegian salmon companies such as SalMar and NRS. The idea is that ocean farming will be more sustainable and eliminate local contamination along the coast. The concept is still under review, and it is therefore to early conclude if this is the future of fish farming.

6.2 Quality

One of the best selling points for Norwegian farmed Atlantic salmon is the product quality. An interesting story from a customer in the US underline this well. The customer sold three different farmed salmon in a test phase to see what had the best demand. It was Chilean, Canadian and Norwegian farmed Atlantic salmon. The Chilean was cheapest, the Canadian was a bit more expansive, and the Norwegian was the most expansive. The customer could report that the Norwegian salmon was out of stock first, then the Canadian, while the Chilean had some leftover. This test proved for the customer that the consumers are prioritizing quality the most.

To ensure food quality and safety, EU has laid down specific hygiene rules for food produced in EU. Norway is not an EU member but are an EFTA member. To be able to be treated as an equal in the trade landscape within EU, Norway do ratify/implement most EU regulations. Regulation No 853/2004 of the European Parliament and of the Council are the specific regulations laid down to ensure food hygiene (EU, 2021). The regulation has its own section dedicated to fishery products. These regulations are covering the entire process from the sea to the consumer. These regulations ensure the product hygiene and should underline how comprehensive regulation Norwegian seafood industry work within to maintain the best quality.

One of the quality marks for whole salmon is the color on the gills. Discolored gills may be a sign that the fish has gone bad or potential gill diseases. This is the main reason why dry ice hasn’t been implemented as cooling refringent for whole salmon, believes Nippon Gases. Usage of dry ice has caused the gills to lose their natural color, turning grey. It has not been proved that dry ice does decrease the quality of the product. In fact, studies point towards better shelf time when dry ice is used instead of wet ice.

If the climate aspect weights the most for consumers, they may have to accept a decrease in product quality. Air freight accounts for up to 97% of the emission in the transport chain. If air freight could be substituted with container freight, the emission would be substantially lower per kg transported. This would mean eliminating transport of fresh salmon, as container freight would mean a much longer transport time. The product would need to be frozen during transport. If customers do want fresh salmon at a lower climate-footprint, new fish farmed must be located closer to the markets. Geographically not all coastlines are suitable for fish farming. Land-based fish farms might be the solution for such countries.

7.0 Conclusions

The Norwegian salmon industry is the world's largest, producing 42 million meals every day (Fisk Media AS, 2022). The Norwegian Government has issued goals that should apply for the seafood industry from 2030. These goals will aim to make Norwegian seafood industry as sustainable as possible (Regjeringen, 2022). To be able to feed the worlds growing population, more food should be produced in the sea. The salmon industry will continue to provide millions of meals a day now and in the future. For a resourceful industry such as the salmon industry, innovation and development towards a more sustainable supply chain can be achieved. It is also up to the Norwegian Government to both facilitate innovation, but also impose regulations to lead the industry towards a sustainable future.

The results on the economical and environmental impact of changing cooling refrigerant from wet ice to dry ice are uniformly in favor of the usage of dry ice. The advice for the processing plants is to investigate the option of implementing dry ice infrastructure.

7.1 Research summary

The economical calculation showed as expected that decreased transport weight will decrease the transportation cost. There is an investment cost to obtain the necessary infrastructure to implement dry ice that needs to be in the equation. The calculations done in this thesis shows that there is considerable cost reduction potential.

From an environmental view dry ice outperforms wet ice due to the reduced transport weight. Considering that salmon export utilizes the most pollutive mode of transport, salmon exporters should urge to minimize the climate-footprint.

7.2 Managerial implications

According to Nippon Gases, dry ice is being implemented in new processing plants being built. The increase in demand for salmon fillets overseas makes it vital to minimize transport cost to stay competitive. Combined with high inflation, increased transport- and fuel costs, its reasonable to believe that salmon fillets exporters that has not implemented an alternative to dry ice, will act. The problem is however to solve the quality issue with dry ice for fresh whole salmon.

From an environmental view, everyone has a responsibility to minimize their impact. Salmon is labeled as the most climate-hostile seafood, both in public and proved to be in reports. It should therefore be in salmon exporters best interest to show that they are trying to minimize their climate footprint. Calculations in this study has showed that reduced weight due to usage of dry ice as cooling refrigerant can reduce greenhouse gas emissions significantly. The most polluted product is the intercontinental exported salmon due to air freight. The air freight market is very price- and capacity dependent, which means that exporters tend to choose the airline that is cheapest and has capacity. According to NTMs baseline to calculate emissions, emission can vary much from older aircraft to new state of the art. It is however ignorant to believe that salmon exporters will select airlines based on aircraft type/new fleet.

7.3 Limitation of the study

In the meeting with Vikenco fall of 2021, their main wish was to figure out how dry ice can be used on fresh whole salmon without it harming the quality. This problem is not within the field of logistics. This study has been limited to the impact it will have economically for the salmon exporters, and environmentally.

In most cases when distances, emissions etc. were calculated there was a need to simplify the input data to make it doable. The transaction list provided by Vikenco had thousands of data lines. In addition, were some data not representative to the average because of different reasons, such as seasonal variances, low volume, or artificially prices. The secrecy in the industry as well makes it difficult to know what each exporter has in transport cost, where are they transporting to and from which airport.

I believe that the calculations are at best within a reasonable assumption of the reality. The potential savings and environmental gain speak for itself, and the 20% factor can be implemented by other exporters in their numbers.

7.4 Suggestion for further research

7.4.1 Discoloring on gills

In chapter 2.1 it was mentioned that it has been experimented on dry ice as replacement for wet ice as cooling refrigerant for fresh whole salmon. Nippon Gases has together with salmon exporters experimented on different methods. Examples are direct application and indirect application. There are several ways of doing this. The two direct applications are:

- Direct application of dry ice
- Hybrid application of wet- and dry ice

The indirect applications are:

- Dry ice in bags
- Dry ice inside the EPS box structure

According to Nippon Gases, the concept that has been most successful is a hybrid solution with both wet- and dry ice. It is believed by Nippon Gases that dry ice does not decrease the food quality. However, discoloring of the gills is seemed like a sign that the fish has gone bad.

If it is possible to find out the cause, it might be possible to solve this problem. It might also be possible to prove that the food quality is maintained, even if there are discoloring on the fish. This can be difficult, since the whole world would need to be educated on the matter.

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