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Climate impact, economy and technology of farmed Atlantic salmon

Documentation of the current state for fresh and frozen products exported to Asia and fresh products to Europe

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Report

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Summary/recommendation:

As a part of the project "Nye metoder for bedre holdbarhet og mer miljøvennlig transport av lakseprodukter" (New methods for improved shelf life and more sustainable salmon products), this report documents the current status of the products exported to Paris and Shanghai from an environmental, economic and technological point of view. Six value chains were studied; head-on gutted or fillet, transported fresh by airplane or frozen by boat to Shanghai and transported fresh by truck to Paris, example value chains chosen to represent important current markets for Norwegian farmed salmon.

The value chain for fresh salmon is well adapted to shipment in EPS-boxes with ice as a cooling media. Alternatives to ice exist, but they have not been implemented on a large scale by the industry. The freezing time can be reduced significantly from today's 12-24 hours which has been reported by choosing existing solutions.
Airfreight dominates the total climate impact of the product, and transporting fillet instead of head-on gutted fish gave a 20 % reduction in climate impact. Also, a frozen product transported by ship to Shanghai resulted in half the climate impact of fresh salmon flown to the same destination.

Cost of transportation is a minor cost component when transportation is by road to Europe, at around 4% of the export price, while airfreight to Asia adds 26 %. Switching from fresh to frozen products for Asian markets has roughly an 85 % cost-saving potential on transportation.

Summary/recommendation in Norwegian:

Denne rapporten dokumenterer dagens produksjon av laks fra et teknologisk, miljø og økonomisk perspektiv. Dagens produksjon av laks er tilpasset bruken av is som kjølemedie, og det er potensiale for bedre metoder for innfrysing av laks. Undersøkelsene viser at ved å gå over fra fly frakt til transport med båt så halveres klimaavtrykket til laksen. Man kan i tillegg redusere med ytterligere 20 % ved å transportere filet i stedet for sløyd laks. Transportkostnadene på vei/bane til Europa utgjør bare 4 % av totalkostnaden, med båt til Asia kan man spare 85 % av transportkostnaden til flyfrakt.

Preface

This report is the first delivery in project FHF-901635, "Nye metoder for bedre holdbarhet og mer miljøvennlig transport av lakseprodukter"[1] (New methods for improved shelf life and more environmentally friendly salmon products) financed by FHF - Norwegian Seafood Research Fund. The project aims to find new technological solutions that reduce the environmental impact, is acceptable for the customers, and increase revenue compared to today's practice. This project is a collaboration between Nofima, RISE and NTNU has a total budget of NOK 3,010,000 and ends in April 2022.

[1] https://www.fhf.no/prosjekter/prosjektbasen/901635/

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1 Existing value chains identified for Norwegian Salmon

In the first phase of this project, we want to establish a basis for comparing the product and transportation solutions we will study. Norwegian salmon is exported to around 150 countries, in different product forms, with varying transport modes and through different routes. It goes without saying that not all product combinations, transport, and routes can be studied here. For practical reasons, we must simplify. Also, by concentrating on a few representative supply chains, we may reach a detailed level that will allow us to consider all relevant aspects of both carbon emissions and packaging and transportation costs.

The following value chains were identified and selected for representing current export chains for Norwegian farmed salmon (*Salmo salar*) to major markets (Table 1), with the purpose to illustrate the potential of the two most important factors 1) filleting before exporting and 2) enabling slower transportation (seafreight instead of airfreight) by switching from fresh to frozen products. The chains represent fresh and frozen salmon that is exported whole (head-on gutted (HOG)) to Asia by air and sea and fresh as whole and fillet (B-trim) to European countries. Also, two chains were added, mainly to see if any improvement potential lies in filleting in Norway before export to the Asian market instead of in Asia as is done today, so exporting fresh and frozen B-trim fillets to Asia. The US is an important additional market for Norwegian salmon, however as logistical chains to the US are relatively similar to the ones to Asia, it was decided not to study export to the US. B-trim was selected to represent a filleted product for comparison to HOG, as it was considered a reasonable average by industry representatives. Several other fillet types are also exported, the potential of which will be studied together with innovative processing and packaging solutions in the work to come.

Table 1 The value chains of Norwegian salmon included in this report

#	Product form	Processing form	Transport mode	End destination
1	Head-on gutted	Fresh	Airplane (direct cargo)	Shanghai
2	Head-on gutted	Fresh	Truck (40 tonnes)	Paris
3	Fillet (B-trim)	Fresh	Airplane (direct cargo)	Shanghai
4	Fillet (B-trim)	Fresh	Truck (40 tonnes)	Paris
5	Head-on gutted	Frozen	Ship (container freighter)	Shanghai
6	Fillet (B-trim)	Frozen	Ship (container freighter)	Shanghai

Most of the salmon exported from Norway is fresh salmon, where HOG is the primary product (Figure 1). However, frozen salmon is popular in some markets, and here fillet is the preferred option.

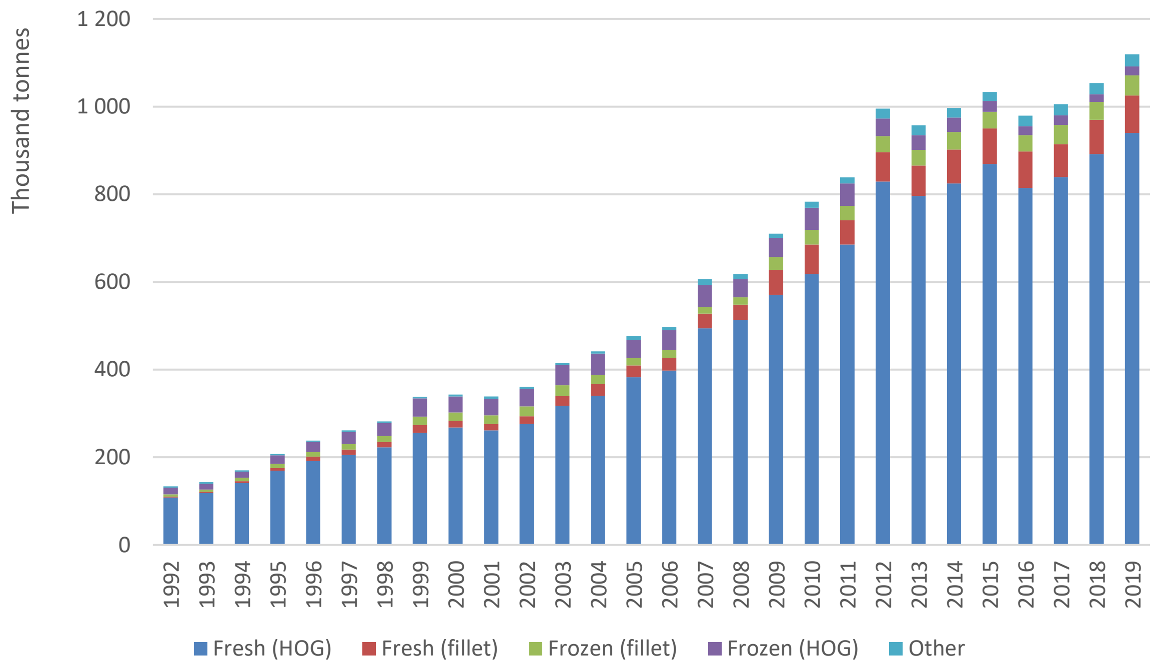

Figure 1 Export of salmon from Norway. Product weight. Source: SSB

Even though fresh fillet production is relatively low, it is important in terms of transport cost and carbon footprint. For airfreight, fillet constitutes a considerable share, which has been increasing. For this project, to assess the potential for carbon emission reductions, this reduction in transport weight must also be considered.

1.1 Climate impact of total current airfreight of Norwegian salmon

Before going into detail on our chosen supply chains, it might be valuable to consider the total carbon footprint of Norwegian salmon's air freight. This is the basis for evaluating potential carbon emission savings.

In Table 2, we have made a rough estimate of carbon emission based on the volume of air freight to overseas markets and the distance from Oslo. By combining tonnes of airfreight with distance, we arrive at a total of close to 1.5 billion ton-kilometers, where a total of 800 thousand tonnes of CO_2 is emitted[2]. To put this in some perspective: this emission is not much shy of emissions from all national air traffic in Norway (about 1 million tonnes)[3].

[2] The assumed emission factor is crucial for this estimate. The emission factor differs between freight and passenger flights, it differs between large and small planes, between intercontinental and regional, between high and low load, whether infrastructure is included or not. A large, long-distance cargo aircraft, for example Oslo-Shanghai, emits 0.49 kg CO2eq/ton*km including fuel production (with maximum load factor and no infrastructure included). Going down to 65% load, it will be 0.62 and within Europe with 50% load it will be 0.975 kg CO2eq/ton*km (Network for Transport Measures, transportmeasures.org). Assuming that most transport is done on large carriers with relatively high load factor, we assume an emission factor of 0.55 kg CO2eq/ton*km.

[3] Numbers on Norwegian air traffic are from Avinor, the operator of Norwegian airports: https://avinor.no/globalassets/_konsern/om-oss/rapporter/avinor-og-norsk-luftfart-2019-no.pdf

Table 2 Total air freight of salmon from Norway in 2019, with estimates of emission of CO_{2eq}.

	Tonnes	Assumed landing town	Distance (from Gardermoen)	Tonn* kilometers	Emission of CO2 (tonnes)
USA	35,444	New York	5,862	207,773,877	114,276
Japan	31,472	Tokyo	8,306	261,407,429	143,774
South-Korea	26,199	Seoul	7,591	198,877,968	109,383
China	23,331	Beijing	6,906	161,125,316	88,619
Hongkong	13,758		8,508	117,052,996	64,379
Thailand	13,756	Bangkok	8,670	119,261,173	65,594
Taiwan	10,771		8,685	93,548,419	51,452
Israel	8,369		3,635	30,422,994	16,733
Singapore	7,905		10,037	79,337,798	43,636
United Arab Emirates	6,754	Dubai	5,145	34,751,347	19,113
Vietnam	4,473	Ho Chi Minh	9,267	41,454,210	22,800
Saudi-Arabia	3,909	Riyadh	4,877	19,063,271	10,485
South-Africa	2,860	Cape Town	10,622	30,374,353	16,706
Canada	1,589	Toronto	5,863	9,315,633	5,124
Morocco	1,472	Agadir	3,748	5,517,742	3,035
Malaysia	1,274	Kuala Lumpur	9,739	12,410,252	6,826
Qatar	1,180		5,038	5,947,062	3,271
Indonesia	1,125	Jakarta	10,925	12,289,926	6,759
Lebanon	942	Beirut	3,532	3,325,961	1,829
Quwait	879		4,884	4,295,248	2,362
Bahrain	518		4,913	2,545,484	1,400
Others (average)	1,969		6,988	2,217,207	1,219
Sum				1,452,315,665	798,774

These calculations must be considered estimates, as they are based on some simplifying assumptions, such as an assumed average for CO_2-emissions, all airfreight leaving from Gardermoen and a single stretch to the destination. In reality, this is much more complex, which is one reason we are limiting the supply chains we study in this report.

The exact transport routes and modes of transportation used vary significantly within each value chain. Some airfreight is done by cargo planes, some in the hull of passenger flights. Some airfreight is done through a direct flight, some over two (or more) transport legs. Some are transported on a combination of cargo and passenger planes. A typical route is to use cargo planes to a hub in the mid-east and then passenger planes to the final destination.

Gardermoen is important for airfreight, with two terminals facilitating salmon's airfreight, but it is not the only route. From Northern Norway to Asia, a much-used route is through Helsinki and passenger flight directly, to for instance, Japan or Beijing. Some salmon is also taken by road to London, Amsterdam or Frankfurt, before going by passenger flight to Asia or the USA.

The different configurations of transport routes mean that exact calculations are complicated. A shorter flight will give lower emissions, for instance, while stops will increase emissions per ton freighted. Later in the project, these calculations will be refined to allow for more precise estimates of carbon- and cost-saving potential.

2 Processing of salmon

A brief survey was carried out amongst Norwegian Salmon producers/exporters to understand how the current practice is for processing salmon, and the following subchapters sum up the feedback.

2.1 Slaughter process of salmon

The processing steps from a live fish in the sea to a fish ready for shipment follow the same steps in all slaughter factories in Norway (Figure 2), namely transport from sea cage to slaughter factory by wellboat, pumping the fish from the fish into the factory, stunning and bleeding, gutting and sorting.

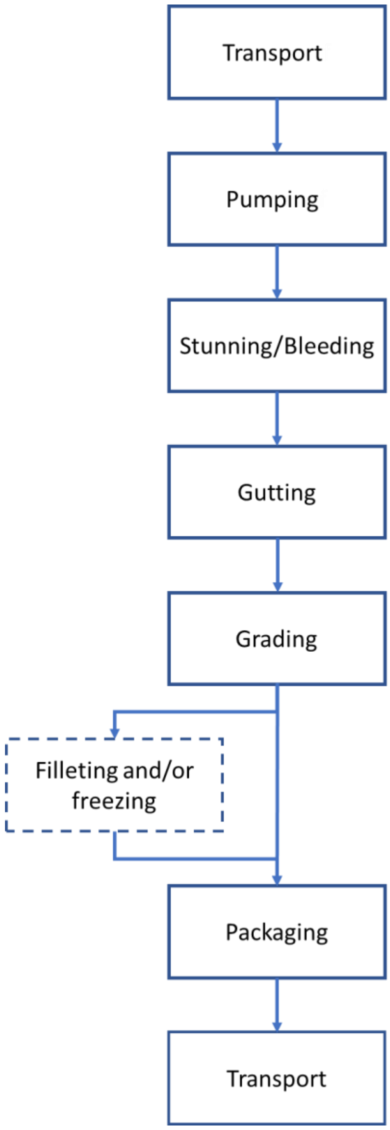

Figure 2 Main steps of processing of farmed Atlantic salmon in Norway.

Typically, a well-boat collects the fish at the sea cage and transports the fish to the factory. The fish can be transported live to the factory, or it can be stunned and bled on board the boat. Some factories prefer to store the fish in waiting-cages, while others pump the fish directly from the well-boat and into the slaughter plant. If live fish is pumped, the fish is then stunned, eighter by percussive or electrical stunning, before the fish is bleed in a tank with chilled water. Then the fish is gutted and cleaned before it is graded. In the grader, the fish is weighed and sorted into different product categories. Fresh HOG is sorted into weight groups (e.g., 3-4 kg or 5-6 kg) and packaged directly, while fish graded for filleting or freezing are sorted out for further processing.

Recently, a new alternative has been entering the market; slaughter boat. This ship includes gutting and chilling in refrigerated seawater on the vessel, and it lands superchilled HOG for packaging or further processing.

2.2 Fresh distribution

The most common solution for fresh salmon packaging and transportation in Norway is using expanded polystyrene (EPS) boxes, where fish is chilled and kept chilled by adding wet freshwater ice.

Slaughtered HOG salmon is placed directly into the box in the grader, and 3-5 kg of ice is added, and the fish undergo *rigor mortis* in the box. The time fish are produced varies according to the facility, volume and season, but in general, fish are packed 2-4 h after harvest. The addition of ice serves two purposes; chilling the fish down to 0 °C and keeping this temperature until it reaches the customer. Transportation is done on refrigerating trucks or containers, which should be four °C or colder, and the ice serves as insurance in case the chilling chain is not working correctly. Also, the amount of ice in the box at delivery is used to evaluate transportation quality. The shelf life of HOG salmon is stated to be 16 to 17 days.

Fillets, however, undergo extra steps before packaging and transportation. After grading, the fish is decapitated and filleted. The fillets are then trimmed to specifications according to the quality requirements of the customers. After cutting and optional skinning, the fillets are packaged in EPS boxes wrapped with plastic lining to avoid direct contact between the ice and melting water and the fish. Shelf life for fillet is stated to be around 12 days.

Production of farmed Atlantic salmon in Norway focuses on the major product, fresh HOG, and facilities that efficiently make it. Several slaughterhouses don't offer to fillet. However, the ones that do typically have a good set up for efficient and sound filleting and logistics to take care of the and further utilize the processing by-products.

There are alternatives to cooling using ice that are not yet widely used, such as super chilling. Super chilling means to chill the fish down to the initial freezing point, or slightly below, which for salmon is around -1.5 °C. Ice is then unnecessary, as chilling capacity is built into the fish as small ice crystals. Super chilling can be performed on HOG salmon in an auger tank or using various freezers when super chilling fillets. However, super chilling is more vulnerable to failures of the chilling chain. There are also alternatives to wet ice, such as gel ice and dry ice. Gel ice is used to avoid drip from melting ice and maintain the chilling capacity over time. On the other hand, dry ice is used when weight is an issue and gives a short chilling period, which often results in a superchilled condition in the box.

Even though alternatives to adding ice for cooling exist, the value chain is adapted to ice, and it seems to be challenging to go for new solutions. From a technological point of view, ice works well, but it adds up to 20 % weight. It acts as insurance for violation of the chilling chain, and it offers a quick evaluation of temperature and quality of the transportation for the receiving customer. However, to reduce weight, alternatives to traditional ice should be implemented in the future.

2.3 Frozen distribution

The freezing technology for HOG salmon and fillet varies; the most common for HOG being tunnel freezing – with a freezing time of up to 12 hours. Individual freezing of fish in spiral freezers is also used. Spiral freezers are more efficient than tunnel freezing and only require 3-4 hours to reach a final core temperature < -30°C. After freezing, the fish is usually glazed in freshwater. Glazing applies a thin layer of ice on the fish's surface and decreases the exposure to oxygen. The potential for oxidate the fat fraction of the fish is then reduced. Some producers subsequently pack each fish in a plastic bag, whereas others use one bag for all the fish before packaging in carton, to further improve the protection against oxygen. The total carton weight may vary, but 22-24 kg of fish is not unusual for 4-5 kg sized fish. Their response indicates that the salmon is subjected to freezing within 1-1,5 hours after slaughter, i.e., *pre-rigor*.

Fillets are frozen with the same equipment, but the glazing step is not included. Freezing times for fillets are reported to be up to 24 hours.

12 and 24 hours signals not optimal freezing technology. It is a well-established fact that a quick freezing process results in superior quality compared to a long process (Dawson *et al.,* 2018). This is related to the size of the ice crystals that are formed during freezing. A quick process results in small ice crystals, while a time-consuming process gives large crystals. Large crystals have a more significant effect on the cell walls and can result in degraded texture and increased drip loss.

The storage period consists of three main elements: In-house storage, storage throughout distribution, and storage at the customer warehouse. The in-house storage temperature is the easiest to control and document. Temperatures between -22 and -25 °C are reported. Usually, the frozen food distribution chain is associated with -18 °C, but this is regarded as being too "high" for fish, and lower temperatures are recommended. To our knowledge, -21 to -23 °C is often chosen for transport, and this is decided by the customer. We do not know anything about the storage temperature regimes in the customer warehouses, other than according to most international regulations, it should be -18°C or lower. Fluctuating temperature can result in growing ice crystals, and hence degradation quality (Dawson *et al.,* 2018)

The shelf life of most frozen food is determined by quality degradation and not food safety aspects. It is well recognized that the quality of fish stored at -20 °C will be reduced with frozen storage time. Hence, shelf life is somewhat governed by the accepted quality degradation associated with a frozen product when stored according to recommendations.

The stated shelf life of frozen salmon is varying between 12 and 24 months.

Thawing of the frozen fish is a crucial step to maintain the quality of the product. There are no recommendations for thawing the fish from the producers, as far as we have experienced.

3 Climate impact of existing value chains

The identification of chains and how they were modeled followed a recent report on the greenhouse gas emissions of Norwegian seafood products (Winther *et al.,* 2020), where the goal was to model typical or *average* Norwegian seafood supply chains, not those of a particular producer. The companies involved in the current project were asked to verify the underlying data used and presented in Winther *et al.* (2020) amongst others regarding routes, type or airfreight, load and packaging, and no substantial differences were identified in this data verification effort. Therefore, the same underlying data was used, and the only modification made was related to by-product use (see below).

3.1 Method and data for calculation of climate impact

The climate impact (also called carbon footprint) of the six different value chains for Norwegian salmon was calculated using Life Cycle Assessment (LCA). The LCA method is used to quantify resource use, emissions and the resulting environmental impacts of each life cycle step of a product. It is widely used to identify hot spots and improvement potentials for products and illustrate the effects of changes made in the value chain (Guinée *et al.,* 2011).

The climate impact was calculated for the functional unit 1 kg of edible salmon (either in the form of whole, i.e., head-on gutted, or fillet). The life cycle steps covered in the assessment include salmon aquaculture (which encompasses feed and smolt production and grow out), slaughter, processing, and all actions to deliver the product to the market country. When co-products emerged in the studied system and were further utilized (e.g., for feed production), climate impact was divided between them based on mass.

By-product utilization in the market (i.e., after export of gutted or B-trim fillet) was set to zero for all chains, despite the data availability in the report by Winther *et al.* (2020) indicating differing by-product use in different markets. This approach was selected to avoid confounding the effect of different product forms and transport solutions with differing by-product use effects. This assumption and the improvement potential in increased utilization of by-products is discussed. As waste is not burdened with any climate impact, using more of the salmon, e.g., for feed, lowers the fillets' climate impact as the climate impact of all upstream life cycle steps is shared between the fillet and the utilized by-products.

Life Cycle Inventory data for the LCA were based on data for transports' modeling in Winther *et al.* (2020). The data was taken from the LCA database Ecoinvent (version 3.5) except for airfreighting, which was modeled using the database Network for transport measures (NTM; www.transportmeasures.org), adapted by specific data provided by companies involved in the logistics of Norwegian salmon exports, e.g., regarding the time of cooling needed during the different transports, routing for pickup and load factors for return trips. All details on the modeling of transport emissions are presented in Winther *et al.* (2020).

Climate impact was assessed using the impact assessment method based on the most recently available factors from the Intergovernmental Panel on Climate Change, IPCC (Stocker *et al.,* 2013) and modeled in the software SimaPro (v.9.1).

3.2 Results on climate impact

For the Shanghai market, the presently available transportation alternatives are air and ship. When air freight was used, it dominated the product's total climate impact, overshadowing all other life cycle steps such as the production of salmon feed ingredients, grow out and processing combined (Figure 3). Consequently, the most dramatic improvement in carbon footprint was seen when air transportation of fresh salmon was replaced by frozen salmon shipping. Transport emissions were reduced by over 90% and total supply chain emissions by around 50%. By switching from using fresh whole salmon to frozen salmon fillets, Asian chefs or consumers can reduce the footprint of their salmon dish by more than 60%.

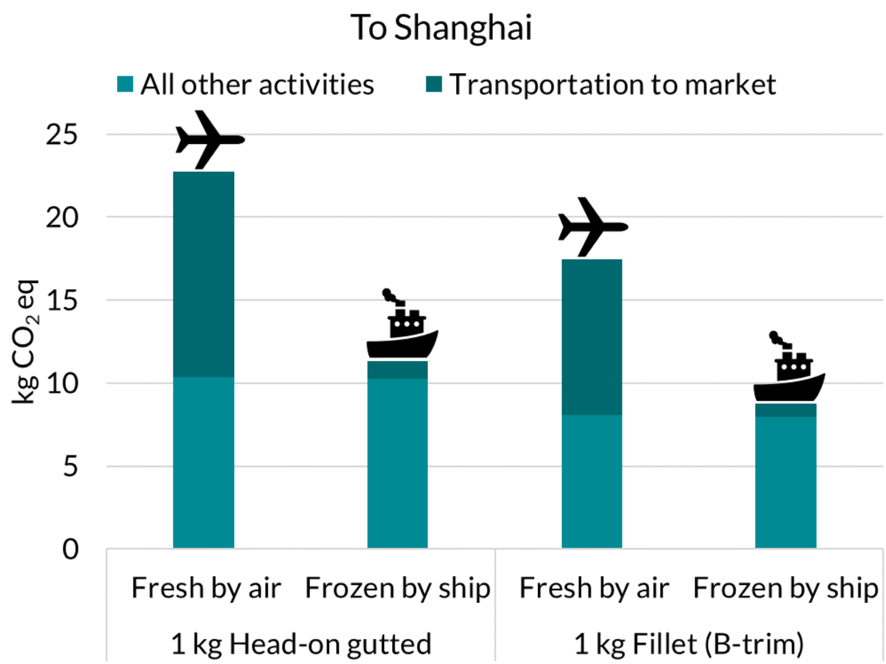

Figure 3 Climate impact of four types of salmon products transported from Norway to Shanghai by two different transportation modes assuming no use of by-products after export. Non-transport activities have slightly lower emissions for fillet than whole because by-product use before export is more extensive than after, and by-products account for a part of upstream emissions when further utilized.

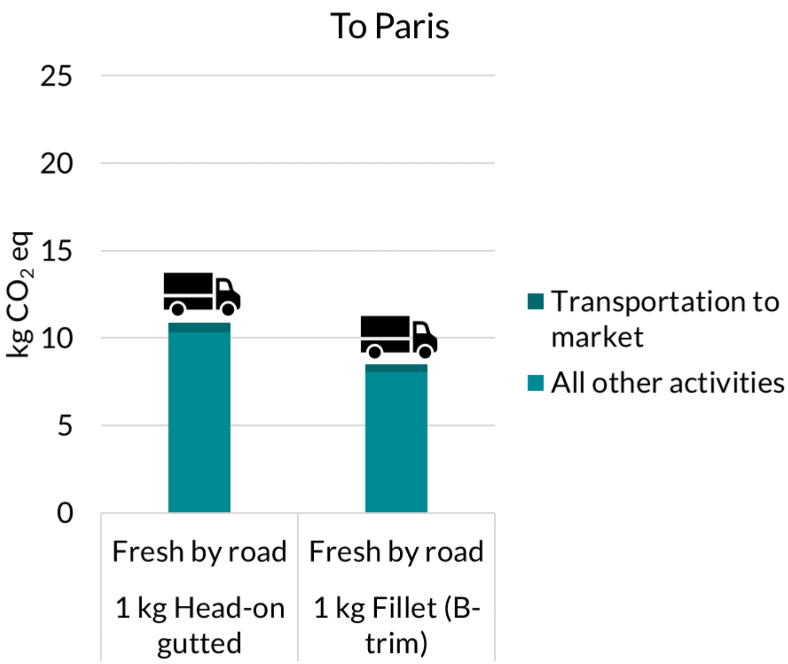

Figure 4 Climate impact of two types of salmon products transported from Norway to Paris by truck.

For salmon transported to Paris, trucking is at present the primary mode of transportation. The truck transport's climate impact from Norway to Paris gave an almost negligible contribution to total supply chain emissions (Figure 4). In the Paris value chains, the climate impact varied with product form. The climate impact was 20 % lower when transporting fillets for the Paris and Shanghai value chain instead of head-on and gutted salmon. There are two reasons for that. One is the decreased volume of edible fish that needs to be transported. The second reason is that by-product utilization in Norway is assumed to be 91 % compared to 0 % in the market, resulting in a larger proportion utilized vs. wasted product when the product is filleted before export.

3.3 Discussion and conclusions of climate impact

Results show a massive difference in climate impact between current value chains of exported Norwegian salmon. The most considerable difference found was between air freight and shipping, where a salmon product shipped to Shanghai had half the climate impact of the same product when flown. Hence, just by a transition towards lower impact transport solutions already existing, the climate impact of a Norwegian salmon product at the end market could be reduced by 20 % to 60 %.

The results for air transportation were strikingly high compared to other transportation modes. However, they can be expected to be on the lower end of the range for air transportation, as the plane type (cargo) and route (direct) etc., assumed were the most effective ones. There were also indications that the assumptions around a load of pickup flights were on the optimistic side and that load on these flights might, in reality, be lower, although both variables are uncertain.

An assumption that would influence the results is the utilization of salmon by-products in the market. Data collection for Winther *et al.* (2020) indicated that by-product use in Asia was much higher for the frozen whole than for fresh whole salmon (70 vs. 20%), and when used, this reduces the emissions of the main product and can further separate product forms from each other (or erase differences). In

France, by-product use was high for whole salmon (80%) but lower for B-trim fillets (30%). There is no data on by-product use for fresh and frozen fillets exported to Asia since these chains are still not fully developed. The extent to which by-products are utilized is often determined by logistics and proximity to potential users. As explained earlier, the assumption of zero use of rest raw material in the market resulted in lower emissions for fillets when the by-products remain in Norway, where they are utilized. If by-product utilization were as high in the end markets as in Norway, the climate impact difference between whole salmon and fillets would be much smaller.

4 Economic analysis

Packaging and transportation might, at first glance, not seem very important. In 2018, packaging (including transportation by wellboat to the slaughterhouse) amounted to 10 % of the production cost for Norwegian salmon, USD 0.47/NOK 3.82 of a production cost of USD 4.65/NOK 37.80 per kilo (Iversen *et al.,* 2020). But as production and production costs are both high, 10 % actually amounts to 4.8 billion NOK.

Also, one needs to consider transportation from the slaughterhouse to the final destination. The customer often pays this (but in that case, it of course affects the price to the producer) and it is not part of Norwegian trade statistics, and thus easily overlooked. The combined costs of packaging and transportation are somewhere in the range of 10-12 billion NOK. These costs are of a magnitude that makes them highly relevant when packaging methods and transportation modes are chosen, and even moderate changes may have considerable cost implications.

That is also the main reason for including costs in this consideration of packaging and transportation methods. With a price of this magnitude, it is expected that if new methods come at a cost disadvantage, their probability of acceptance will be dramatically reduced.

Primary purpose of this section is to establish a base cost for packaging and transportation, to which new solutions will be compared.

In Table 3, we have shown the estimated cost of production for whole salmon (HOG) and fillet for our three supply chains. Production costs for major cost components are sourced from (Iversen *et al.,* 2020), while the more specific costs related to packaging (labor, box, ice, absorbent) and transport are calculated for this project, based on interviews with a sample of producers. These costs are to be considered specifications of the Harvest/Packaging cost.

Table 3 Cost to destination for salmon through our chosen supply chains. Cost in USD.

	Shanghai				Paris	
	Fresh by air		Frozen by ship		Fresh by road	
	1-kilo HOG	1-kilo fillet	1-kilo HOG	1-kilo fillet	1-kilo HOG	1-kilo fillet
Smolt	0.52	0.73	0.52	0.73	0.52	0.73
Feed	2.20	3.10	2.20	3.10	2.20	3.10
Labour	0.42	0.59	0.42	0.59	0.42	0.59
Miscellaneous	0.74	1.04	0.74	1.04	0.74	1.04
Depreciation	0.31	0.44	0.31	0.44	0.31	0.44
Harvest/Packaging	0.47	0.66	0.47	0.66	0.47	0.66
Labour	0.16	0.40	0.22	0.62	0.13	0.37
Box	0.21	0.15	0.17	0.12	0.17	0.12
Ice	0.01	0.01			0.02	0.02
Absorbent			0.03	0.02		
Cost of Production	4.57	6.51	4.61	6.67	4.52	6.41
Sales cost	0.18	0.26	0.18	0.27	0.18	0.26
Transport to final destination	1.70	1.70	0.31	0.31	0.19	0.19
Cost to destination	6.45	8.49	5.10	7.24	4.89	6.86

This table shows that while transport cost is a modest addition to the production cost for fresh salmon by road, it is a major addition to airfreighted salmon: it adds around 25% to the production cost. It also shows that shifting from fresh by airfreight to frozen by ship will cut about 85% of transportion costs to Asia.

Costs of packaging are calculated based on the assumptions in Table 4. Prices vary according to product form, packaging process, and type of transportation. Costs also vary between firms, depending on factors like size, age and technological solutions, here we have used information from a sample of producers and use their average as a starting point.

Table 4 Cost of packaging and some assumptions.

		NOK/tonn	NOK/hour	NOK/kilo	USD/kilo
Labour	Fresh/road	3.53	300	1.06	0.130
	Fresh/air	4.36	300	1.31	0.161
	Frozen	6	300	1.80	0.221
Box	Fresh/road	1,400		1.40	0.172
	Fresh/air	1,680		1.68	0.207
	Frozen	1,400		1.40	0.172
Ice/absorbent	Fresh/road			0.20	0.025
	Fresh/air			0.12	0.015
	Frozen			0.21	0.026

Costs of shipping are calculated based on the assumptions of an average freight cost for airfreight of NOK 14. Freight is also calculated for road transport from the slaughterhouse to Gardermoen. Here we assume NOK 1.50 per kilo. This means that the total calculated cost for air freight is NOK 15.50. The cost for air freight varies by distance, but also between different stretches with similar distances. The price of air freight depends a lot on the level of capacity utilization for the given routes. The capacity for air freight between Asia and Europe is generally determined by demand from East to West. Hence, lower capacity utilization from West to East has greatly benefited Norwegian salmon exports, with relatively low prices for airfreight. But even though this is a general trend, there are huge differences between different locations in Asia, and also seasonal variations. For our purpose, an average freight rate is considered an adequate solution, though.

Freight by road is usually charged by the truck for a given distance. Shipment per kilo might be NOK 2.50 from Northern Norway and 1.50 from Southern Norway. We assume an average of NOK 2 per kilo.

Table 5 Cost of shipping, based on assumed averages.

	NOK/tonn	NOK/kilo	USD/kilo
Fresh/road	1,500	2.00	0.185
Fresh/air	14,000	15.50	1.698
Frozen	2,500	2.50	0.308

5 Overall summary

The following point sums up the findings in this report:

- The value chain for fresh salmon is well adapted to shipment in EPS-boxes with ice as a cooling media.
- Alternatives to ice exist, but they have not been implemented on a large scale by the industry.
- Even though good technological solutions exist for freezing both HOG and fillet, freezing times from 12-24 hours are reported. By using more efficient technologies, the time can be significantly reduced, giving improved quality.
- The temperature should be consistent and well below -18 °C throughout the value chain.
- More focus should be set on the thawing step.
- When air freight is used, it dominates the total climate impact of the product.
- The climate impact was 20 % lower when transporting fillets to the market instead of whole salmon both in the Paris and Shanghai value chain.
- A salmon product shipped frozen to Shanghai had half the climate impact of one transported fresh by air. By a transition towards existing lower impact solutions, the climate impact of Norwegian salmon products could be decreased by 20 % to 60 %.
- Cost of transportation is a minor cost component when transportation is by road to Europe, adding around 4% of the cost.
- Cost of transportation is a major cost component when airfreighting to Asia, adding 26% to the cost.
- Switching from fresh to frozen products for Asian markets has roughly an 85 % cost-saving potential on transportation

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