UiT The Arctic University of Norway

Faculty of Biosciences, Fisheries and Economics

Carbon Footprint and Nutrient Density of Underutilized Norwegian Marine Resources

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Front page: Sustainability illustration based on pictures from Mostphotos.com and A. Langdal.
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This thesis has been an amazing journey from being stuck in Canada and exchanging mails with supervisors about topics I wanted to work with; deep-diving in research on nutritional recommendations and carbon emissions in food production; methodology discussions in, and across research institutions; creating several life cycle assessments; until, in the end, I was able to create this thesis. And I have enjoyed every moment of it.

However, COVID-19 have influenced us all in one way or another. So, I want to reach out with my gratifications to everyone fighting to keep us all safe, and my deepest sympathy to all those who have faced, and is still facing the consequences of COVID-19.

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Summary

Both nationally and internationally, there is a rising ambition to reduce carbon footprint to fight climate change. However, climate change should not be seen as a solitary challenge as the human population has more than tripled since the 1950ths. We are therefore moving towards the inevitable crossroad where the food needed to sustain humanity and the traditional utilized resources we have available, cannot keep up. At the same time, current food production is responsible for around 26 - 31 % of global greenhouse gas (GHG) emissions. The aim of this thesis was therefore to analyse the micro- and macronutrients and grade them according to a nutrient density score (NDS), as well as estimate the carbon dioxide equivalent emission of underutilized and potential novel marine resources. Thus, working as a guidance for more sustainable food alternatives.

Orange-footed sea cucumber (*Cucumaria frondosa*) is low in energy-providing nutrients, scored mediocre on micro- and macronutrients compared to the other species but scored lower when the nutrients were capped at 100 % of the daily recommended intake (DRI). The emissions were mediocre, both compared to the other species analysed, and when compared with other protein sources such as commercially available seafood species and terrestrial animals. The diatom *Porosira glacialis* requires further analysis but contains a high proportion of marine long chained polyunsaturated fatty acids. Northern krill (*Meganyctiphanes norvegica*) was mediocre in energy-providing nutrients, scored high on micro- and macronutrients compared to the other species, but mediocre when the nutrients were capped. Pearlside (*Maurolicus muelleri*) was high in energy-providing nutrients, scored high on micro- and macronutrients compared to the other species, and mediocre when the nutrients were capped. The emissions of the pearlside were low compared to standard marine ingredients used in salmon feed. Atlantic herring (*Clupea harengus*) was high in energy-providing nutrients, scored mediocre on micro- and macronutrients compared to the other species, and low when the nutrients were capped. The emissions of herring are heavily influenced by by-product utilization but scores among the best when compared to commercial seafood species and terrestrial animals per *kg* edible, per 100 *grams* protein, and per 1000 *kcal*. In summary, the orange-footed sea cucumber scores the best according to the NDS without capping, the pearlside scores best in energy-providing nutrients, while the herring scores best for GHG emissions and according to the NDS with capping.

Sammendrag

Både internasjonalt og i Norge er det økende ambisjoner om å redusere karbonutslipp for å motvirke klimaendringene. Samtidig kan ikke klimaendringene sees isolert eller som vår eneste store utfordring, siden den globale populasjonen er tredoblet siden 1950-tallet. Vi beveger oss derfor mot den uunngåelige utfordringen at matressursene, ikke dekker behovet for mat til klodens befolkning. Matproduksjon representerer også pr. nå mellom 26 og 31 % av de globale klimagassutslippene. Derfor har målet med denne masteroppgaven vært å analysere innhold av mikro- og makro næringsstoffer i uutnyttede, og potensielt nye marine arter. Videre ble disse artene rangert ved bruk av ernæring gradering, og estimat av utslipp av klimagasser, slik at vi i framtiden kan basere oss på de mest bærekraftige matalternativene.

Brunpølse (*Cucumaria frondosa*) inneholder lite energirike næringsstoffer, middels av mikro- og makronæringsstoffer sammenlignet med de andre artene som ble analysert, men lavere på innhold av mikro- og makro næringsstoffer når næringsstoffene ble begrenset ved 100 % av daglige anbefalte inntak (DRI). Klimaavtrykket er middels, både sammenlignet med de andre artene, og med andre proteingivende kilder slik som kommersielt tilgjengelige sjømatprodukter og landdyr. Kiselalgen *Porosira glacialis* må undersøkes videre, men inneholder en høy andel av marine langkjedede flerumettede fettsyrer. Norsk storkrill (*Meganyctiphanes norvegica*) inneholder en middels mengde av energirike næringsstoffer, mye mikro- og makronæringsstoffer sammenlignet med de andre artene, og middels på mikro- og makronæringsstoffer når næringsstoffene ble begrenset ved DRI. Laksesild (*Maurolicus muelleri*) er rik på energirike næringsstoffer, og mikro- og makronæringsstoffer sammenlignet med de andre artene, men middels på mikro- og makronæringsstoffer når næringsstoffene ble begrenset ved DRI. Klimaavtrykket av laksesild viser et potensiale sammenlignet med ordinære marine ingredienser brukt i laksefôr. Sild (*Clupea harengus*) er rik på energirike næringsstoff, inneholder en middels mengde av mikro- og makronæringsstoffer sammenlignet med de andre artene, men skårer lavt på mikro- og makronæringsstoffer når næringsstoffene ble begrenset av DRI. Sildens totale klimaavtrykk påvirkes mye av anvendelse av bi-produkter, men skårer blant de beste produktene når den sammenlignes med kommersielt tilgjengelig sjømat og kjøttprodukter fra landdyr, både pr. *kg* spiselig andel, pr. 100 *gram*, og pr. 1000 *kcal*. Oppsummert skårer brunpølsen best på ernæringskår hvis ernæringsskåren ikke begrenses av DRI, laksesild skårer best på innhold av energirike næringsstoffer, mens sild skårer best på klimagassutslipp og når ernæringsskåren begrenses av DRI.

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Abbreviations

Carbon dioxide equivalents	$CO_2eq.$
Chilled seawater	CSW
Daily recommended intake	DRI
Dichloromethane	DCM
Docosahexaenoic acid	DHA
Eicosapentaenoic acid	EPA
Energy percentage	E%
Fish meal	FM
Fish oil	FO
Global warming potential	GWP
Greenhouse gases	GHG
Head-on, gutted	H&G
Hydrochlorofluorocarbons	HCFC
Hydrofluorocarbons	HFC
Live weight	LW
Life cycle assessment	LCA
Methanol	MeOH
Maximum recommended intake	MRI
Monounsaturated fatty acid	MUFA
Metric ton/1000 kg	Ton
Nutrient density score	NDS
Polyunsaturated fatty acid	PUFA
The Arctic University of Norway	UiT
Saturated fatty acid	SFA
Sulfuric acid	H2SO4

1 Introduction

Both nationally and internationally, there is a rising ambition to reduce carbon footprint (United Nations, 2015b). The report *Global warming of 1.5°C* from The Intergovernmental Panel on Climate Change (IPCC) states that keeping the peak global warming to 1.5 ºC would grant clear benefits to reduce climate-related risks. Examples of such are threats to human health, -livelihoods, -food security, -human security, and to economic growth (Masson-Delmotte *et al.*, 2018). However, climate change should not be seen as a solitary challenge. The human population has grown rapidly in the latest centuries and has more than tripled since the 1950ths (United Nations, 2019). We are therefore moving towards the inevitable crossroad where the food needed to sustain humanity and the traditional utilized resources we have available, cannot keep up. Further, to ensure global food availability, three predominant challenges need to be accounted for: Energy deficiencies, excessive net energy intake, and nutrient deficiencies, also referred to as the Triple burden of malnutrition. Each category of malnutrition interacting with various infectious and chronic diseases, alongside influencing the resistance/severity of numerous diseases (Pinstrup-Andersen, 2007). At the same time, current food production is responsible for around 26 - 31 % of global greenhouse gas (GHG) emissions (Poore and Nemecek, 2018) and staying within our total global carbon budget is fundamental to averting future global warming. Therefore, it is essential to search for and utilize novel nutritious food sources to keep up with the growing population without overextending the current CO_2 budget.

1.1 Energy deficiencies

In 2015 we faced, for the first time in a decade, an increase in undernourishment globally. Nine percent of the global population were severely food insecure (unable to fulfill their energy needs) and twenty-five percent were moderately to severely food insecure (struggling or worrying about access to a healthy balanced diet) (Roser and Ritchie, 2013), with Sub-Saharan Africa (22 % prevalence), western Asia (13 % prevalence) and Central America (12,4 % prevalence) being affected heaviest (FAO *et al.*, 2020). This challenge worsens with the development of COVID-19 and how it impacts the supply and demand of food production. Though the severity of COVID-19 is still uncertain, a prognosis proposed by FAO (2020) expects more than a ten to fifteen percent increase in hunger for 2020 and three to seven percent increase in 2030 (FAO *et al.*, 2020). It is noteworthy that even if undernourishment is challenging for any age, children's risk is particularly of concern as undernourishment represents nearly half of all deaths in children under five years old (UNICEF, 2020). Alongside, children risk developing stunting (low height-for-age), which has been found to correlate with increased and irreversible physical and neurocognitive damage (Onis and Branca, 2016). The prevalence of stunting has been reduced from 33 % to 22 % in the last two decades, however, UNICEF still quotes it as alarming and that the reduction is going to slowly to reach targets like the sustainability development goals (UNICEF, 2020). The impact of COVID-19 is likely to increase the prevalence of stunting, though UNICEF, WHO and World Bank Group (2021) points out that household survey data on child height and weight, could not be collected in 2020 due to physical distancing policies. It is therefore difficult to confirm this.

In Norway, the Norwegian Directorate of Health has quoted that the access to food is both broad and sufficient. In 2018, an average Norwegian diet consisted of 75 *kg* of meat and meat products, 82 *kg* of grains, 49 *kg* of potato and potato products, 78 *kg* of vegetables, 87 *kg* of fruit and berries, 29 *kg* of round weight fish pr. person pr. year, as of 2018 (The Norwegian Directorate of Health, 2020).

1.2 Excessive net energy intake

The prevalence of excess energy consumed has been increasing worldwide, except in parts of Africa and parts of Asia, resulting in a corresponding increase of overweight (BMI ≥ 25) children and adolescents, (Ritchie, 2017; UNICEF, 2020). A further increase may create a scenario where childhood/adolescents obesity surpass moderate/severe underweight by 2022, according to Abarca-Gómez *et al.* (2017). The main concerns for childhood/adolescent obesity are that it's likely to lead to lifelong overweight and obesity (Singh *et al.*, 2008), increased risk/earlier onset of chronic disorders such as type 2 diabetes (Litwin, 2014; World Health, 2016), adverse psychosocial consequences and lower educational attainment (Caird *et al.*, 2013; Quek *et al.*, 2017; World Health, 2016). Correspondingly, adult (>18 years) overweight and obesity (BMI ≥ 30) is also growing globally in every region (except parts of Asia and Africa), with 39% of adults now categorized as overweight or obese (Ritchie, 2017).

In Norwegian context there is a lack of national statistics for overweight and obesity, but it has been estimated that 50 % of male adults and 39 % of female adults, between 40 and 45 years old, are categorized as overweight. Alongside, 25 % of male adults and 21 % of female adults, between 40 and 45 years old, are categorized as obese (The Norwegian Institute of Public Health, 2017). Dietary factors are among the top ten risk factors for deaths in Norway in 2015 for every age group (Knudsen *et al.*, 2017).

1.3 Nutrient deficiencies

A third nutritional challenge is the growth in poor quality diets and, consequently, increasing lifestyle-dependent diseases (Lim *et al.*, 2012) such as ischaemic heart disease and stroke, which now are the leading cause of deaths (WHO, 2018). In order to ensure nutritional coverage, four different aspects has been recommended to be achieved: Food variety (within and across food groups), adequacy (sufficiency of nutrients or food groups compared with requirements), moderation (food and nutrients that should be consumed with restraint) and overall balance (composition of macronutrients intake) (INDDEX Project, 2018). However, which nutrients is lacking in different regions might vary depending on individual characteristics and cultural context (FAO *et al.*, 2020).

From a Norwegian dietary perspective, the average diet is below recommendations for vitamin D, folate (vitamin B_9), iron for young adults (18-40 years), and should substitute saturated fatty acids with polyunsaturated fatty acids (Valen *et al.*, 2020; The Norwegian Directorate of Health, 2019; National Council for Nutrients, 2017). There has also been measured a concerning low consumption of iodine in parts of the population (The Norwegian Directorate of Health, 2019). This is particularly problematic in young/pregnant women, where insufficient maternal iodine intake is associated with subfecundity, reduced fetal growth, adverse pregnancy outcome, and reduced school performance and language delay in the children (Abel *et al.*, 2020; Abel *et al.*, 2019)

1.4 Climate impact of food production

The annual, global GHG emissions are estimated to be around 49.1 *Gt* CO_2*equivalents* (eq). with agriculture, land use, land-use change, and forestry, emitting a quarter of this (World Resources Institute *et al.*, 2019), while fishery is estimated to emit 179 *Mt* CO_2*eq*. (Parker *et al.*, 2018). The emissions of food production is, however, not distributed equally throughout the production chains and as of 2018, 18 % was emitted from the supply chain, 31 % from livestock and fisheries, 27 % at crop production, and 24 % from land use (Ritchie, 2019).

Currently, Norway is in the top quartile of CO_2 emissions pr. inhabitant (Worlddata, n.d.; Eurostat, 2020) with 6.35 million tons CO_2*eq*. coming from the Norwegian agricultural industry (Grønlund and Harstad, 2014), and 0.99 million tons CO_2*eq*. from the Norwegian fishery industry (Hognes and Jensen, 2017). This made food production close to 13.62 % of the Norwegian total GHG emissions in 2014 (The Norwegian Environment Agency, 2020). In order to keep in line with the Paris agreement, our emissions need to be reduced (Ministry of Climate and Environment, 2020) because on our current global development for GHG emissions, the UNs Secretary-General Guterres has quoted: “Climate change is moving faster than we are” (Masson-Delmotte *et al.*, 2018).

1.5 Diet groups

As shown, the complexity of the triple burden of malnutrition effects every society and nation. Alongside, the carbon footprint of food production is substantial. Thus, it might prove useful to define what nutrients the different food groups offer, and the carbon dioxide emissions released throughout the production

1.5.1 Diets high in meat

Meat consumption has been on the rise since 1960 (Godfray *et al.*, 2018) but in the latest decades FAO *et al.* (2020) reports that red meat availability has grown most in upper-middle-income countries. Alongside, high-income countries show consistently a high degree of red meat availability, with low-income and lower-middle-income countries consistently showing a low degree of meat availability (FAO *et al.*, 2020). Bennett’s law, a well-established empirical relationship, points out the positive correlation between a population’s income, and diets incorporating expensive calorie sources like meat, over traditional starch-rich diets (Bennett, 1941; Godfray *et al.*, 2018). As such, meat consumption has contributed to increased protein availability and essential nutrients like iron, zinc and vitamin B12 to vast populations (McAfee *et al.*, 2010). On the other hand, this increased consumption has raised several challenges where red- and processed meats have been associated with increased amount of lifestyle dependent diseases like rectal cancer (The Norwegian Directorate of Health, 2011).

Current GHG emissions related to Norwegian meat production in carcass weight have been calculated at 2.4 - 4.95 $kg\ CO_2eq$ (eq). Kg^{-1} pork and 1 - 3.3 kg $CO_2eq.\ Kg^{-1}$ chicken, between cradle (farm) and retail gate (distributor) (Grønlund and Mittenzwei, 2016; Oort and Andrew, 2016). For beef (Dairy cows within Norwegian standards), there is a lack of post-farm data, making its total GHG footprint > 19.5 kg $CO_2eq.\ Kg^{-1}$, though Norwegian beef production has shown lower yields and higher methane emissions per *kg* product compared to neighboring countries. Therefore, it could be stated that the Norwegian production is at least higher than West-European production at 21.22 kg CO_2eq. Kg^{-1}. However, a typical factor that is often omitted in life cycle assessments (LCA) for meat production is land use, and land-use change emissions, which can significantly contribute to the final emissions for beef (and/or milk) (Oort and Andrew, 2016).

1.5.2 Diets high in plants and plant products

Another food source of importance is the use of plant and plant products (vegetables, legumes, cereals, fruits etc.) to cover people's nutritional demands as well as reduce the GHG emissions from food (Tilman and Clark, 2014). Research has documented that even the lowest-impact animal production typically exceeds those of vegetable substitutes regarding to environmental impact (Poore and Nemecek, 2018). However, some of this diet's main weaknesses have been its low content of protein/essential amino acids, calcium, iodine, iron, vitamin B12 and long-chained polyunsaturated omega-3 fatty acids (LC-PUFA-n-3). Although some of these nutrients have been found in vegetarian diets, it has been shown that their bioavailability is lower (American Dietetic Association, 2009; Key, Appleby and Rosell, 2006; Lane *et al.*, 2014).

Carbon footprint of plant and plant products, Nymoen and Hille (2012) estimates carbon-friendly food delivered to Norwegian nursing homes. However, they note how several vegetables do have poorer growth potential in Norway and poorer storage stability in general. The CO_2eq. footprint is only presented when Norwegian resources are at their peak availability. For root vegetables and cabbage, they estimate 0.125 - 0.375 $kg\ CO_2eq.\ Kg^{-1}$, potatoes at 0.175 - 0.575 $kg\ CO_2eq.\ Kg^{-1}$, onions at 0.19 - 0.57 $kg\ CO_2eq.\ Kg^{-1}$ and tomatoes and cucumbers at 0.84 - 1.56 $kg\ CO_2eq.\ Kg^{-1}$. For grains, 82 % of all food quality grains in the Norwegian diet was reported as wheat in 2018 (The Norwegian Directorate of Health, 2020), which has an emission of 0.56 - 1.28 $kg\ CO_2eq.\ Kg^{-1}$ (Nymoen and Hille, 2012)

1.5.3 Diets high in seafood

A third food source of importance is seafood from both wild fisheries and aquaculture. Seafood covers 17 % of the global production of edible meat and is a vital pillar for food security in many countries (Costello *et al.*, 2020), and an important contributor of bioavailable micronutrients (Kawarazuka and Béné, 2011). Some of these nutrients particularly calcium, iron, and zinc are present at a higher level in tropical species. Meanwhile, species in colder regimes/pelagic feeding is found to have a high omega - 3 concentrations and smaller species (both consumed whole and as fillet) is found to contain a high concentration of calcium and iron in addition to omega - 3 fatty acids (Hicks *et al.*, 2019). However, as of 2017, only 6.2 % of fish stocks remain underfished, and 34.2 % are fished at biologically unsustainable levels (FAO, 2020), reducing its potential for increasing food production.

Within Norwegian seafood production, GHG emissions for cradle (fish/farm) to retail (distributor) are estimated to be at 6.4 - 8.4 $kg\ CO_2eq.\ kg^{-1}$ edible salmon for salmon aquaculture, while the GHG emission for demersal species (cod, haddock and saithe) is estimated to 1.6 - 2.5 $kg\ CO_2eq.\ kg^{-1}$, and pelagic species (mackerel and herring) is estimated to 1.1 - 1.4 $kg\ CO_2eq.\ Kg^{-1}$ (Winther *et al.*, 2020). Though it must be noted, as more than 80 % of salmon, 60 % of herring and 50 % of cod is exported (Norwegian Seafood Council, 2021; Statistics Norway, 2020a; 2020b), the GHG emissions from production gate to retail gate will vary dependent on the market. And as shown by Winther et al. (2020) this could increase the carbon footprint for salmon up to 19.4 $kg\ CO_2eq.\ kg^{-1}$.

1.6 Purpose of thesis

The need for alternative nutritious food sources with minimum emissions of GHG is pressing. Therefore, the aim of this thesis was to analyse the macro- and micronutrient, as well as estimate the GHG emission through $CO_2eq.\ kg^{-1}$ of underutilized and potential novel marine resources. The species analyzed were: Orange-footed sea cucumber (*Cucumaria frondosa*), the diatom *Porosira glacialis*, northern krill (*Meganyctiphanes norvegica*), pearlside (*Maurolicus muelleri*), and Atlantic herring (*Clupea harengus*). Lastly, the same species were compared to common food sources to rank the species potential as sustainable food sources.

2 Material and methods

The orange-footed sea cucumber was collected by divers at 10-15 *meters* depth in Northern Norway (N 69°35.795, E 18°56.047) outside Tromsø in February 2021. The sea cucumbers were stored in seawater for a few hours until delivered at UiT- The Arctic University of Norway, where they were frozen. Before analysis, the internal organs, mouth, anus, and aquapharyngeal bulb were removed. The body wall of the orange-footed sea cucumber was then cut into smaller pieces and homogenised with an HR1364/00 hand mixer (Philips, Netherland).

The monoculture of *P. glacialis* was grown at Finnfjord AS, as part of a pre-industrial development project and delivered to UiT in frozen blocks. Biomass is harvested from a continuous culture maintained in the exponential growth phase in 300 000 *liters* vertical column photobioreactor using seawater collected at 25 *meters* depth in the Indre Finnfjordbotn water reservoir. The biomass is then put through a drum filter and frozen. The water used is filtered using 1 μm polypropylene filters (Model GX01-9 7/8, GE Power & Water, USA) and added inorganic nutrients in the form of $0.25\, mL\, L^{-1}$ Kristalon and $1\, mL\, L^{-1}$ dissolved natriummetasilicate (3.5 *gram*s $Na_2O_3Si.9H_2O$ L^{-1} in milli-Q water (Merck KGaA, Darmstad, Germany)). The photobioreactor was subjected to the natural environment of Finnfjordbotn (N 69° 13.76′, E 018° 05.02′) and kept temperature between 8 and 11 $°C$ during the entire cultivation. The culture was aerated with flue gas containing 6 – 12 % CO_2 and maintained at pH 7.4 – 8.1.

The northern krill and the pearlside were caught with an adapted pelagic trawl in June/July 2019, by Liegruppen AS, at 175 depth, around N 59° 30.′, E 03° 21 in Norskerenna (Bjorkdal and Thorvaldsen, 2019). All catches are shown in appendix 1. Initially, a sample from catch number 16 was weighed and sorted into batches of fish, krill, and a mixture $^2/_3$ fish and $^1/_3$ krill, which were used for all analyzes except micronutrients. The batches were grinded with a meat grinder (Bosch, Germany) to a paste before analysis. For micronutrients, new batches were sorted, from catch number 15, in a refrigerated room to avoid denaturation.

The herring was caught north-east of Trænabanken with a pelagic trawl on the 11th of February 2021, by Asbjørn Selsbane, NO, and kept cool with refrigerated seawater. It was landed in Senjahopen on the 12th of February and frozen round. The herring was kept frozen and transported to UIT where it was filleted and skinned before being cut into smaller pieces and homogenised with an HR1364/00 hand mixer (Philips, Netherland).

Pictures of all samples, pre homogenisation, are shown in figure 1. All samples were frozen to -80 C° and freeze-dried with a VirTis Genesis 35 EL (VirTis SP Scientific, NY, USA) for 48 hours. Results given in wet weight have been achieved through multiplying the dry-weight results by the ratio between wet weight and dry weight, except for results from water (2.1.1), ash (2.1.2) and micronutrients (2.1.6)

Figure 1. All species prepared for analyses with orange-footed sea cucumber (Cucumaria frondosa) top left, northern krill (Meganyctiphanes norvegica) and pearlside (Maurolicus muelleri) top right, herring (Clupea harengus) bottom left, and a diatom (Porosira glacialis) bottom right.

2.1 Proximate analyses

2.1.1 Water content

Water content was measured according to AOAC 950.46B as described by AOAC International (2019a) on all samples. Four replicates were made by weighting 10 *grams* of wet weight sample and dried in a heratherm oven (ThermoFisher Scientific, Waltham, US) at 105 *°C* until the weight stabilized (2-4 days). The water content was calculated with the use of formula 1.

$$\text{Water percentage} = \frac{Weight\ before\ drying - Weight\ after\ drying}{Weight\ before\ drying} * 100\% \qquad (1)$$

2.1.2 Ash content

Ash content was measured according to AOAC 938.08 as described by AOAC International (2019b). The Four replicates from chapter 2.2.1, were combusted at 540 *°C* for 16 hours in a muffle furnace (Nabertherm, Lilienthal, Germany). The ash content was then calculated with formula 2.

$$\text{Ash percentage} = \frac{Weight\ after\ drying\ and\ combustion}{Weight\ before\ drying\ and\ combution} * 100\% \qquad (2)$$

2.1.3 Lipid content

The lipids from the orange-footed sea cucumber, the mesopelagic species and the herring were extracted with a modified version of Folch, Lees and Stanley (1957) on freeze-dried material with four replicates. Heptadecanoic acid (Supelco Analytical, Bellefonte, PA, US) was used as the internal standard (10 *mg* heptadecanoic acid / *ml*, 2 : 1 dichloromethane (DCM) (vWR chemicals, Leicestershire, UK) : methanol (MeOH) (vWR chemicals, Leicestershire, UK)) and dichloromethane was substituting chloroform. 0.5 *gram* sample was placed in a 15 *ml* centrifuge tube with 9.5 *ml* 2:1 DCM:MeOH. For the mesopelagic species and herring, 0.5 *ml* (10 mg/ml) internal standard were added and mixed for 25-30 *minutes* in a Multi Reax (Heidolph Instrument, Germany). However, for the orange-footed sea cucumber, 0.25 *ml* internal standard was added before the sample was mixed for 30 *minutes* in a test-tube rotator (Labinco, Breda, Netherland). Afterwards the samples were centrifuged in a multifuge 1 S-R (Heraeus, Germany) on 4000 *g* for 10 *minutes* which resulted in the solid particles being confined to the bottom of the tube. The liquid was poured into new containers, and added 2 *ml*, 0.9 % NaCl solution. This mixture was then blended with a Reax 2000 (Heidolph Instrument, Germany) for 15 seconds, before centrifuged at 2000 *g* for 10 *minutes*. With the samples now divided in two layers. The upper layer was removed with a glass pipette, and the lower layer was moved to a pre-weighted glass tube. The glass tube was then flushed dry with N_2 gas by a Sample Concentrator SBCONC/1 (Stuart-equipment, Staffordshire, UK) and re-weighted. The lipid percentage was then calculated with formula 3.

$$\text{Lipid percentage} = \frac{Glass\ tube\ with\ lipids\ from\ sample}{Amount\ sample} * 100\% \tag{3}$$

2.1.4 Fatty acids

Fatty acid composition was determined by methylation and gas chromatography according to a modified version of the method described by Stoffel, Chu and Ahrens (1959). The lipid samples from chapter 2.1.3. were diluted to 100 $mg\ mL^{-1}$ then to 10 $mg\ mL^{-1}$ in a solution of 2:1 DCM:MeOH. 100 μl of each sample were then combined with 900 μl DCM and 2 *ml* 2% H_2SO_4 in methanol (1960 μl Methanol + 40 μl 37 % H_2SO_4 (Honeywell - Fluka, Charlotte, North Caroline US)) in glass duram tube and heated in a heating block (ThermoFisher Scientific, Waltham, US) at ~100°*C* for one hour. The tubes where then added 3.5 *ml* heptane (vWR chemicals, Leichestershire, UK) and 3.5 *ml*, 5 % NaCl solution and mixed. The upper lipid layer was then moved into new tubes and flushed dry with N_2 gas (AGA AS, Oslo, Norway) through a Sample Concentrator SBCONC/1 (Stuart-equipment, Staffordshire, UK). The samples where dissolved in 100 μl heptane and transferred to gas chromatography tubes and analyzed by an Agilent 6890N Gas chromatograph equipped with a 7683B autoinjector and flame ionization detector. (Agilent Technologies, Santa Clara, CA, US). The carrier gas used was helium and the capillary column was a varian CP7419 (50 *m* × 250 μm × 0.25 μm). The temperature of the injector was 240 °*C* and the temperature of the detector was 250 °*C*. A pre-programmed temperature setting is used in the column oven, which is designed to get the best possible separation of the fatty acids in the sample. The amount of the various lipids was calculated according to the amount internal standard (IS) added in the samples with formula 4.

$$\frac{Amount\ Fatty\ acids}{100\ gram\ sample} = \frac{Peak\ area\ FA}{Peak\ area\ IS} x \frac{Amount\ of\ IS\ added\ (g)}{Weight\ sample\ (g)} {*}100 \tag{4}$$

2.1.5 Amino acids

To determine the amino acid composition, 40 *mg* dried material was mixed with 0.7 *ml* distilled un-ionized H_2O from a Milli-Q: Millipore (Merck KGaA, Darmstad, Germany), 0.5 *ml*, 20 *mM* internal standard DL-Norleucin (Merck KGaA, Darmstad, Germany), and 1.2 *ml* 37% HCl (Honeywell, Charlotte, North Caroline, US) in glass tubes with two replicates. The samples were then covered with N_2 gas for 15 seconds and put in a Heratherm oven on 105-110 *°C* for 24 hours. 1 *ml* sample was then centrifuged in an Eppendorf centrifuge 5424 R (Eppendorf, Hamburg, Germany) on 14000 *g* for 3 *minutes* for the herring filet, and 6 *minutes* for the diatom, the orange-footed sea cucumber, and the mesopelagic species. 100 *μl* was transferred to a new glass tube and dried inn with N2 gas through a Sample Consentrator SBCONC/1 (Stuart-equipment, Staffordshire, UK), and then dissolved with 1 *ml* 2.2 pH Lithium citrate buffer. Samples were analyzed with a Biochrom+ Amino Acid Analyzer (Biocrom C, Cambringe, UK) with a lithium citrate-equilibrated column and post-column derivatization with ninhydrin. Measured signals are analyzed with Chromeleon Software (Dionex, Sunnyvale, CA, USA). The amino acids were then compared with a standard curve with a physiological amino acid standard (Supelco A6407 (Acids and neutrals) and Supelco A6282 (Basics)) to identify and quantify the amino acids. The total amount of protein was measured as the sum of amino acid residues as recommended by FAO (2003) through formula 5.

$$\sum_{1}^{17} \frac{Molecular\ weight\ amino\ acid - molecular\ weight\ water}{Molecular\ weight\ amino\ acid} \qquad (5)$$

2.1.6 Micronutrient

All micronutrients used in this thesis has either been adapted from the literature or analyzed by an accredited laboratory (Institute of Marine Research, Bergen) and are shown in table 4, alongside their sources.

2.2 Carbon dioxide equivalent assessment

The emissions from the potential novel species were estimated by mimicking a method used by Winther et al. (2009) and Winther er al. (2020) by allocating the emissions from cradle (fishery/cultivation) to retailer (distributor) according to mass. With both studies using one or both of the ISO standardized life cycle assessment (LCA) methodology 14040 and 14044 to describe climate impact and energy use. System boundaries for an LCA are shown in figure 2. To ensure equal resource utilization, the functional unit (the production goal of the system) was calculated according to 1 *kg* of edible product at retail. All by-products resulting from the production chain used in other products are allocated their emissions according to mass, equally to the main product. In contrast, by-products not utilized in other products has their emissions added to the main product.

One advantage of allocating emissions according to mass, according to the ISO standard, is that it encourages the food industry to use the by-products by putting a high environmental burden on them. At the same time, the parameters used, are stable, making year-to-year comparisons more feasible. On the other hand, it places the same environmental burden on all parts of the landed fish, fillets, mince, as well as non-edible parts used in one way or another by the production of fish meal (FM), fish oil (FO) etc. (Winther *et al.*, 2020).

This thesis has not been controlled by an external review in accordance with the ISO standard for LCA's of public product comparisons (Winther *et al.*, 2009). Thus, the estimates may only be used as a guidance for further research.

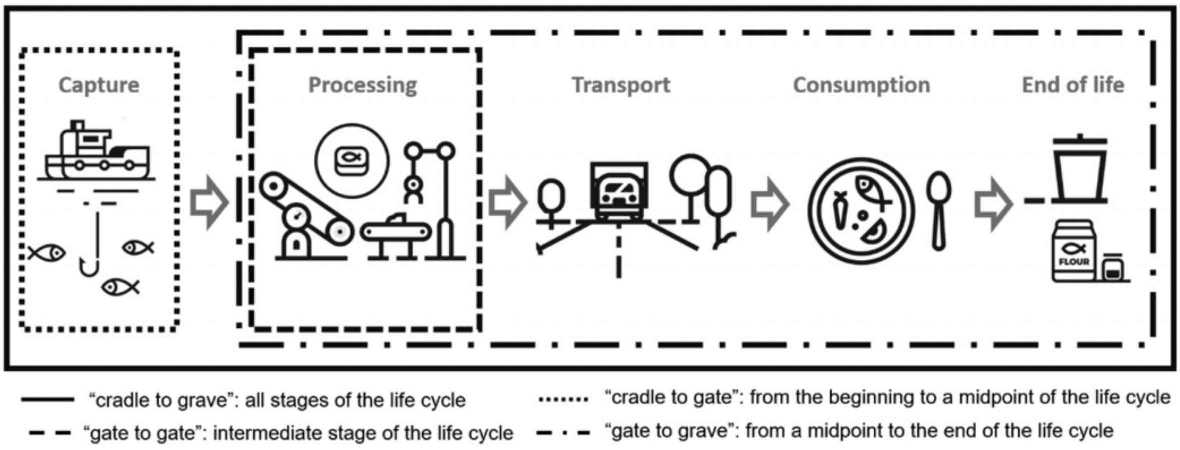

Figure 2.Common system boundaries applied in lifecycle assessments for seafood (Ruiz-Salmón et al., 2021)

2.2.1 Carbon dioxide assessment model for herring

As shown in chapter 1.5.3, only 40 % of the harvested herring is used domestically. The model is thus developed for export. In 2019 the herring export was 54 % whole herring, with Egypt and Nigeria being the dominant importers, and 30 % frozen filets with Poland being the dominant importer (Norwegian Seafood Council, 2021). Thus, in this model, herring filets are transported from Tromsø, Norway to Gdansk, Poland and whole herring to Alexandria, Egypt. Alexandria is chosen due to it being the port with the highest trading rate in Egypt (Egyptian Maritime Data Bank, 2020). The production chain used in this model assumes that the herring is either caught in Norway, landed-, gutted-, filleted-, frozen-, packaged and stored in Tromsø before transport to Poland, or it is caught in Norway, landed-, frozen-, packaged-, and stored in Tromsø, while transported to, and filleted in Egypt. Further details are given in chapter 2.2.1.1 – 2.2.1.4 and Figure 3.

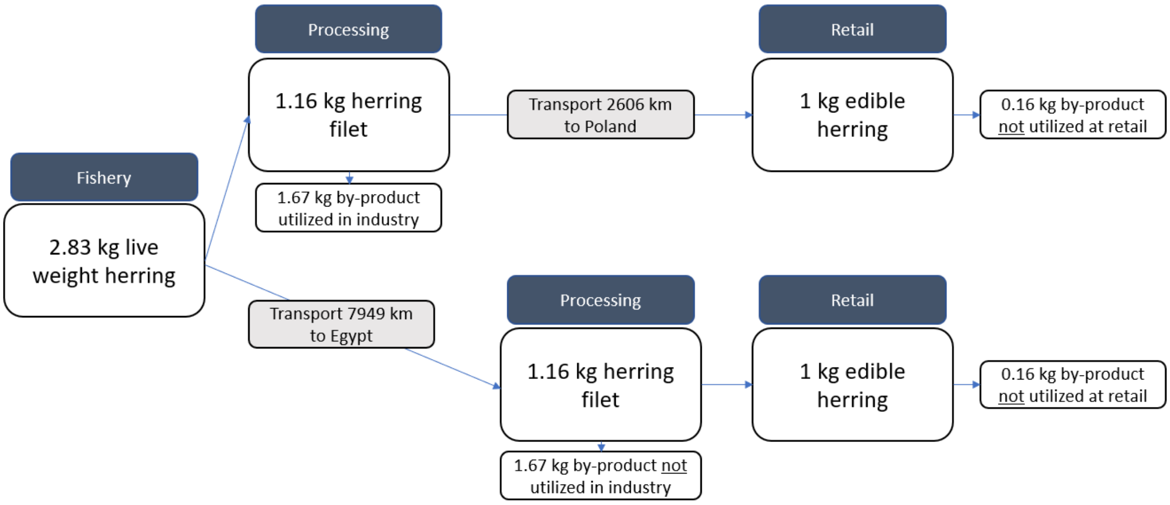

Figure 3. Flowchart of modelled production chain for herring (Clupea harengus) between cradle and two different retail gates (Poland and Egypt).

2.2.1.1 Herring fishery

The construction of the fishing vessel is usually not a significant contributor to emissions on fish products and is therefore not taken into account. In 2017, 58.3 % of herring was caught with purse saine with an average fuel use of 0.10 *liter/kg* live weight fish (LW) and emitting 3.2 $kg\ CO_2eq./liter$ fuel (Winther *et al.*, 2020). Fuel use for cooling is negligible (Widell and Nordtvedt, 2016). However, it is known that traditional cooling agents have high carbon footprints. Winther *et al*. (2009) reported that hydrochlorofluorocarbons (HCFC) particularly here HCFC-22 or R22, had a global warming potential (GWP) of 1810 *kg* CO_2*eq./kg*, whereas other common cooling agents like CO_2 and ammonia have a GWP of 1 and 0 *kg* CO_2*eq./kg* respectively (California Air Resource Board, n.d.). The ratification of international regulations (Official Journal of the European Union, 2014) have resulted in reduced greenhouse gas (GHG) emissions from the Norwegian fishing fleet, and a part of this has been attributed to the change in cooling media (Bjørndal *et al.*, 2019). As of 2017, ammonia and CO_2 are the most common cooling agents in Norwegian fisheries, according to Hognes and Jensen (2017). Though, the same authors mention that several fishing vessels have introduced “drop in” mediums to replace R22, which also have a considerable GWP. To take this into account, Winther et al. (2020) calculated that the average emissions could be 0.008 *kg* HFC/*ton* landed for coastal purse seine. However, without knowing which mediums are used to replace R22, R22 is used as a benchmark, even though the footprint of the agents used as “drop in” refrigerants could be substantially higher (Hognes and Jensen, 2017).

2.2.1.2 Herring processing in Norway

It is estimated that the herring were fileted at the same energy efficiency as at a whitefish plant, using 661 *kWh/ton* fish (Winther *et al.*, 2009). Freezing is estimated to be at the same efficiency as in pelagic industry plants calculated by Winther *et al*. (2020) at 216 *kWh/ton* LW fish and 0.13 *liter* fuel/*ton* LW fish. Storage is estimated by using the assumptions given in Winther *et al*. (2020), with fish density at 444 *kg* fish/*m3*, storage volume utilization at 0.75, days of operation at 250, and the electricity used at 78 *kWh/year/*m^3, while average frozen storage would be 90 days according to Winther *et al*. (2009).

As electricity, the average European grid mix, with a GHG emission of 0.44 *kg* CO_2*eq./kWh is* used for calculation (Winther *et al.*, 2020). The European grid mix is used instead of a NORDEL or a pure Norwegian electric grid mix because only 14% of the electricity used in Norway has guarantees of origin, as pointed out by Winther *et al*. (2020). An average of 2.44 *kg* LW fish is needed to produce one *kg* of machine cut fillet without skin and bone (The Norwegian Directorate of Fisheries, 2021) and 86.1% of the filet are edible (Winther *et al.*, 2020). Thus, an estimate of 2.83 *kg* LW fish is expected per *kg* edible product. All by-products is being used in other products (Myhre *et al.*, 2020) and the accumulated emissions to this point in the production chain is therefore equally allocated between filets and by-products.

2.2.1.3 Herring packaging & transport

The fillets and the whole herring were chosen to be packed in cardboard boxes of 2 kg holding 25 *kg* (Winther *et al.*, 2020). The transport distance was determined using Sea-distances.org, determining the distance Tromsø, Norway – Gdansk, Poland to 2606 *km*, and Tromsø, Norway – Alexandria, Egypt, to 7949 *km*.

The transport emissions varies based on available data and calculation parameters. In Winther *et al.* (2009), transport is estimated to emit 35 *grams* CO_2*eq./ton*km* for bulk transport with cooling, while Winther *et al.* (2020) estimates it to 57 *grams* CO_2*eq./ton*km* with transport being contained to inland waterways, and on a barge with reefer kept freezing. On the other hand, using a calculator from the Network for Transport Measures, it is indicated that the journey could emit 100 *grams CO2eq./ton*km* with a bulk carrier at 2000 deadweight-tonnage (DWT), and 30 *grams* CO_2*eq./ton*km* with a container ship with max load of 25000 *ton*. The maximum and minimum estimates are therefore used as an estimate of uncertainty, while the average is used for calculation.

2.2.1.4 Herring processing in Egypt

The fileting in Egypt is assumed to be as efficient as in Norway, but with Egyptian electricity made from 50.7 % oil, 44.7 % natural gas, and 0.5 % coal (EIA, 2018) emitting 0.966 *kg* CO_2*eq./kWh* (EIA, 2020), 0.49 *kg* CO_2*eq./kWh*, and 0.82 *kg* CO_2*eq./kWh* respectively (Schlömer *et al.*, 2014). Due to a lack of data, it is assumed that by-products are wasted and not used in other products

2.2.2 Carbon dioxide assessment model for the orange-footed sea cucumber

With the orange-footed sea cucumber being a novel resource in Norway, the calculations are performed according to the closest relatable production chain. For export, it is assumed that the main market would be in The Peoples Republic of China as noted by Hossain, Dave and Shahidi (2020) and transport would probably go to Shanghai as China’s most active port (World Shipping Council, 2021). It is, however, expected that the product might have an intermediate stop in Rotterdam, Netherland as done in similar export estimates (Winther *et al.* 2009). This results in a transport route of 2248 *km* from Tromsø, Norway – Rotterdam, Netherland, and 19

492 km from Rotterdam, Netherland - Shanghai, Peoples Republic of China (Sea-Distances, 2021). Thus, the orange-footed sea cucumber is expected to be caught in Norway, gutted and kept cool on the fishing vessel, landed-, cooked-, dried-, packed-, and stored in Tromsø, shipped to Rotterdam, and then shipped to Shanghai. Further details are given in chapter 2.2.2.1 – 2.2.2.3 and Figure 4.

Figure 4. Flowchart of modelled production chain for orange-footed sea cucumber (Cucumaria frondosa) between cradle and retail gate (Peoples Republic of China). Sum of the by-products and edible product not corresponding with total amount caught, is due to rounding.

2.2.2.1 Fishery of orange-footed sea cucumber

The most common fishing equipment for the orange-footed sea cucumber found in Canadian and Islandic sea cucumber fisheries are dragnets and beam trawls (Jónasson, 2020; FAO, 2010). However, due to lack of data on fuel consumption, it is assumed the fuel use could be similar to bottom trawling. Winther *et al.* (2009) calculated the fuel use for bottom trawl to be 0.43 ± 0.24 *liter/kg*, however, since this is the total fuel consumption, it includes processing and freezing on board.

Handling of sea cucumber post catch may differ. On one side, Canadian governmental research, recommends immediate evisceration and cooling in seawater (Department of Fisheries and Aquacultures Canada, n.d.). On the other side, other literature points out that the sea cucumber are kept alive until delivery on land for evisceration (Gianasi *et al.*, 2020). However, since slaying and gutting are included in the energy use of bottom trawling trawls (Winther *et al.*, 2009), it is modelled as if the sea cucumber is gutted at sea.

Gutting removes roughly 50 % of the total body weight, with internal organs usually discarded as waste, while keeping the body wall as the main product (Hossain, Dave and Shahidi, 2020). However, sea cucumbers autolyze when stressed or taken out of seawater, so iced seawater is recommended as transport medium to avoid skin necrosis and ensure quality (Gianasi, Hamel and Mercier, 2016). Thus, chilled seawater (CSW) is expected to be used in a potential sea cucumber fishery. The fuel used for cooling and cooling agent is still expected to be negligible (Winther *et al.*, 2020; Widell and Nordtvedt, 2016). For "drop in" medium, the closest relatable fishery is demersal trawlers, which Winther et al. (2020) estimated to emit 0.007 *kg* HFC/*ton* landed for. R22 is still used as a benchmark value.

2.2.2.2 Processing of orange-footed sea cucumber

For processing, cooking before drying is a common treatment of orange-footed sea cucumber (Hossain, Dave and Shahidi, 2020; Department of Fisheries and Aquacultures Canada, n.d.). Cooking was determined according to the formula 6. The parameters were set to e_{hu} at 5.8E-4 (ceramic hot plate with lid), m_w 1000 *grams*, e_{mt} 5.2E-6, t at 30 *minutes* (Department of Fisheries and Aquacultures Canada, n.d.), e_{hp} at 3.7E-6 (ceramic hot plate with lid), m_p 430 *grams* (common weight of our orange-footed sea cucumbers), and ΔT 90.

$$E_{tot} = e_{hu} * m_w + e_{mt} * m_w * t + e_{hp} * m_p * \Delta T \qquad (6)$$

E_{tot} is total energy used (mJ), e_{hu} is the energy used per gram water, m_w is the amount of water used fo boiling, e_{mt} is the energy needed per gram water multiplied by minutes, t is time cooked, e_{hp} is the energy per gram product multiplied by temperature (°C), m_p is the amount of product to cook, and ΔT is the temperature elevation in the product. Formula adopted from Sonesson, Janestad and Raaholt (2003).

For drying calculations, several different values are given in literature. After discussing with a representative from Algetun AS, a Norwegian producer of dried red sea cucumber (*Parastichopus tremulus*) it was decided to calculate drying efficiency as energy usage per *kg* water removal (*kWh*/*kg* H_2O). Algetun AS provided two examples of such water removal estimates. One example was from the industrial producer Munters, who had a water removal efficiency of 1.25 *kWh*/*kg* H_2O. The other example was from their own production which had a water removal efficiency of 0.58 *kWh*/*kg* H_2O (Ragnvald Maartmann-Moe, CEO at Algetun AS, E-mail, November 2020). By expecting a final product with 20 % moisture, it will require 0.75 *kWh*/*kg* to dry sea cucumber with Munters equipment, and 0.35 *kWh*/*kg* with Algetun AS's equipment. To model a scenario for future the orange-footed sea cucumber processing, both examples are used, with Munters as a baseline, and Algetuns as an estimate of a minimum value.

For storage, the scenario used in Winther *et al*. (2020) is not applicable for sea cucumber due to their calculations being based upon parameters like storage volume utilization, which was not accessible for dried sea cucumber. It is therefore chosen to use a more generic storage scenario for fish as given in in Winther *et al.* (2009). This methodology gives two scenarios for storage with either cold storage for 5 days or frozen for 90 days. Since dried sea cucumber is of no rapid risk for denaturation, decomposition it is assumed that it could be stored for 90 days. To preserve the quality, reduce microbial growth and oxidation of the product, it is assumed that cold storage will be necessary as for dried fish (Joensen *et al.*, 2019). This results in an energy use for storage at 0.438 *kJ*/*kg***day* (Winther *et al.*, 2009), though 6.4E-8 *kg* refrigerant 134a/*kg* fish**day* from Winther *et al.* (2020) is added. The average European grid mix with a GHG emission of 0.44 *kg* CO_2*eq.*/*kWh* is still used (Winther *et al.*, 2020) and HFC-134a has a GWP of 1430 CO_2*eq.*/*kg (European Enviroment Agency, 2020)*. Lastly, to ensure 1 *kg* of edible product, a 5 % loss of nutrients is assumed at rehydration, as nutrients may leach out of the food particle during rehydration as noted by Berk (2009).

2.2.2.3 Packaging & transport of orange-footed sea cucumber

The orange-footed sea cucumber is expected to be transported in bags of 250 *grams* dried sea cucumber/1000 cm^3 (1 *liter*) by comparing commercial packages (Seacoo, n.d.; Eir of Norway, n.d.; Atlantic sea cucumber, n.d.) to available packages. It is then expected to be put in cardboard boxes. Packaging material is not included in the weight. The size of the cardboard boxes is estimated to 0.0654 m^3 (Winther *et al.*, 2020).

The transport emissions are assumed to 57 *grams* CO_2*eq.*/*ton***km* to Rotterdam when transported on inlands waterways, with a barge with reefer and kept frozen. To Shanghai it is assumed 22 *grams* CO_2*eq.*/*ton***km* as trans-oceanic sea transport with cooling. (Winther *et al.*, 2020). In contrast, Winther *et al.* (2009) notes how a large containership is estimated to release 18 *grams* CO_2*eq.*/ton*km without cooling. However, it is expected that the cooling would give a significant addition to the emissions. But, due to the lack of information on running times for refrigeration systems on cargo ships, the emission values given by Winther et al. (2009) between Narvik, Norway – Rotterdam, Netherlands at 56 *grams* CO_2*eq.*/*ton***km* and

Rotterdam – Qingdao, China at 37 *grams* CO_2*eq./ton*km* were adapted. To create an estimate, NTMcalc.com was used alongside the values from Winther et al. 2009 and 2020. NTMcalc estimates 30 *grams* CO_2*eq./ton*km* Tromsø – Rotterdam (regional containership at 2000 *ton* carry capacity) and 22.8 *grams* CO_2*eq./ton*km* Rotterdam – Shanghai (oceanic containership at 25 000 ton carry capacity). The max and min values are used as an estimate of uncertainty, while the average is used for calculation.

2.2.3 Carbon dioxide assessment model for mesopelagic species

With the mesopelagic species northern krill and pearlside being a novel fishery in Norway, the calculations are performed on the closest comparable production chain. Pearlside and northern krill are not used for direct human consumption, but as feed ingredient in aquaculture (Winther *et al.*, 2020; Axelsen, 2019). The model is therefore calculated with the mesopelagic species as part of Atlantic salmon (*Salmo salar*) diet, since farmed salmon represents 94 % of Norwegian total aquaculture production (Statistics Norway, 2020b). The reduction process from raw-material to oil and meal is however not included due to time constraint. One of the major salmon importers of Norwegian salmon is France (Norwegian Seafood Council, 2021), so the retail gate for the LCA is chosen to be Paris. Thus, it is assumed that the mesopelagic species were caught in Norway, kept cool, delivered to a feed mill, and used as part of a salmon feed. The salmon is then raised, gutted, packed, and transported to Paris, France. Further details are given in chapters 2.2.3.1 – 2.2.3.4 and Figure 5.

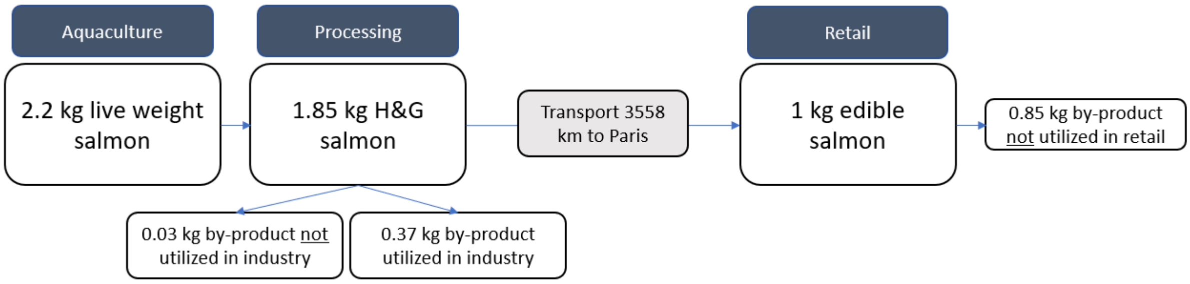

Figure 5. Flowchart of modelled production chain for Atlantic salmon (Salmo salar) between farm gate and retail gate (France).

2.2.3.1 Mesopelagic fishery

Mesopelagic species are harvested using a pelagic or demersal trawl (Bjorkdal and Thorvaldsen, 2019). However, taking the size of pearlside (4-6 *cm*) and northern krill (2,6-5 *cm*) into account (Alvheim *et al.*, 2020) a much finer mesh is needed to catch such species compared to for instance herring (30 *cm*), mackerel (*S. scombrus)* (30 *cm*), capelin (*M. villosus)* (15 *cm*) or blue whiting (*M. poutassou)* (22 cm*)* (Froese and Pauly, 2020; Bjorkdal and Thorvaldsen, 2019). Thus, data from a krill ((4.2 *cm*) fishery were used to estimate the harvest emissions of a mesopelagic fishery (Krafft *et al.*, 2010). To support this, the average size of a commercial krill fishery trawl mesh is at 1.6 *cm* (Krag *et al.*, 2014), whereas for the mesopelagic fishery, the cod-end (last 4 *meters)* of the trawl was at 1.1 *cm* (Øystein Lie, Senior Advisor at Liegruppen AS, E-mail, January 2021).

The fuel use in krill fishery of 0.141 *liter/kg* was used (Cashion, Tyedmers and Parker, 2017). The CO_2eq. from the fuel is at 3.2 $kg\ CO_2eq./liter$ (Winther et al. 2020). Mesopelagic species are easily autolyzed (Axelsen, 2019) and freezing before delivery was assumed necessary. However, this would have a small impact on the footprint (Widell and Nordtvedt, 2016). Though, it is expected 3 *grams* "drop in refrigerant"/*ton* fish landed, mimicking the value for pelagic trawls in Winther et al. (2020). R22 is still used as a benchmark value. It was assumed that the fish was delivered direct to the feed mill without any storage and GHG emissions of 45 *kg* CO_2/*ton* for transport to the feed mill was adapted (Winther *et al.*, 2020).

2.2.3.2 Salmon aquaculture

To calculate the emissions of replacing ordinary ingredients with mesopelagic fish, it is necessary to subtract the emissions of the species already used in salmon feed, and then add the footprint of the novel biomass. However, as salmon feed need to cover a wide variety of essential amino acids, micronutrients, and fatty acids (Aas, Ytrestøyl and Åsgård, 2019), the use of one novel resource to replace all feed ingredients is not possible. Its therefore chosen to replace the closest lipid- and protein containing ingredients from within the same taxonomy class. It is assumed that the oil and fish meal produced from the mesopelagic species, is similar to the species it replaces. This method was however difficult to apply to the northern krill and the mixed batch due to lack of representative species and data to replace.

Pearlside, is chosen to replace mackerel (18.6 % fat) and Norwegian pout (*T. esmarkii*) (12.4 % protein) (Winther *et al.*, 2020), as the species with the closest lipid/protein content found in accordance to Institute of Marine Research (n.d.). This indicates that pearlside could produce 18.6 *kg* oil and 18.8 *kg* fish meal pr 100 kg fish. In ordinary salmon feed, mackerel contributes 0.05 % of the feed as fish meal, and 0.09 % as fish oil, while pout contributes 0.43 % as fish meal, and 0.17 % as fish oil (Winther *et al.*, 2020). The emissions for pout and mackerel ingredients delivered at the feed mill is at 1.4 and 1.3 *kg* CO_2*eq*. Feed conversion rate is assumed to be at 1.32 *kg* feed per *kg* fish, and the GHG emissions for one *kg* LW salmon with traditional feed ingredients is assumed to 5.3 *kg* CO_2*eq*. at farmgate (Winther *et al.*, 2020).

2.2.3.3 Salmon processing

Fresh whole salmon is the dominant export product and is mostly sold head-on and gutted (H&G) (Fauske, 2019). For 1 *kg* H&G 1.2 *kg* LW salmon is needed, but for 1 *kg* grade A trim machin cut salmon fillet, 1.579 *kg* LW salmon is needed (The Norwegian Directorate of Fisheries, 2021). The edible portion of this fillet is 71.1 % (Winther *et al.*, 2020).

By-products and waste are assumed to be the weight difference between whole fish and H&G, and between H&G and edible fillet. For the processing plant's waste, 93 % is utilized as other products (Myhre *et al.*, 2020). It requires 107 *kWh* and 0.13 *liter* fuel per ton LW fish to process salmon from LW to H&G. This includes energy input at the processing plant, which covers the energy used for slaughtering, gutting, cooling, storing, as well as waste handling (Winther *et al.*, 2020). As energy the average European grid mix with GHG emission of 0.44 *kg* CO_2*eq./kWh* is still used (Winther *et al.*, 2020).

2.2.3.4 Salmon packaging & transport

Expandable polystyrene (EPS) boxes, weighing 0.6 kg and carry 20 kg fish and 5 *kg* ice per box each are used for packaging. The total GHG footprint of EPS boxes, from the production of the boxes and up until compressed for material recycling, is at 3.2 *kg* CO_2*eq*. per box (Winther *et al.*, 2020).

For transport, it is assumed that the salmon will be transported 3558 *km* from Tromsø to Paris, France (Network for Transport Measures, n.d.). The carbon emissions of road transport without refrigeration is estimated to 76 *grams* $CO_2eq./ton*km$. Refrigeration it is expected to add 0.38 *gram* of the cooling agent R452A and 2.5 *liter* fuel per *hour* to the total emissions (Winther *et al.*, 2020). R452A has a GWP of 2141 CO_2eq. (California Air Resource Board, n.d.). The time spent driving was estimated to 95 *hours*, assuming an average speed of 50 *km*/*hour* as done in Winther *et al.* (2020), at a maximum of 9 *hours* driven per day, per driver (Norwegian Public Roads Administration, 2020). Though, to reduce the transport time, the truck uses two drivers. On the other side, according to Network for Transport Measures, a truck with 28 - 34 ton trailer capacity, carrying a maximum of 25 tons in accordance with European regulations, would use 82.5 *grams* $CO_2eq./ton*km$ (Network for Transport Measures, n.d.).

2.3 Nutrient score calculation

The nutrients were ranked in accordance with the nutrient density score – C (NDS-C) and NDS-G, from Hallström et al. (2019). Both scoring systems grades nutrients per 100 *grams* of product with no weighing (increasing value of particular nutrients according to the need of a population). However, NDS-G also applies capping (removing additional score from nutrient surplus higher than the daily recommended intake (DRI)), while NDS-C do not.

The calculation was performed by summarizing the nutrients divided by their DRI, and subtracting the dis-qualifying nutrients divided by their maximum recommended intake (MRI) as shown in formula 7 & 8. The DRI and MRI are shown in appendix 2

$$\text{NDS-C} : \sum_{i=1}^{x} \frac{Nutrient\ i}{DRI\ i} - \sum_{j=1}^{y} \frac{Nutrient\ j}{MRI\ j} \tag{7}$$

$$\text{NDS-G} : \sum_{i=1}^{x} \frac{Nutrient\ i}{DRI\ i} - \sum_{j=1}^{y} \frac{Nutrient\ j}{MRI\ j}. \text{ (Nutrients are capped at 100\% of DRI)} \tag{8}$$

NDS is the nutrient density score, x the number of qualitive nutrients, y is the number of dis-qualitiative nutrients, i is amount nutrient, and j is amount dis-qualitative nutrient. DRI is the daily recommended intake of qualitative nutrients and MRI is the maximum recommended intake. All calculations are done per 100 grams of uncooked seafood products.

3 Results

3.1 Proximate composition

In this thesis, the major lipid contributors were the herring and the pearlside, which roughly contained seven to twelve times that of the lowest lipid contributor. Herring, northern krill and pearlside contained the most protein, twice the value of the orange-footed sea cucumber, and six times the amount of the diatom. The ash contents of the different species had lower maximum and minimum values, with the herring consisting of 1.8 % ash, and the diatom at the highest with 6.1 % ash. For water, the fish have similar levels, while the northern krill, sea cucumber and algae, were ten, fourteen and sixteen percentage points higher.

Table 1. Proximate composition of lipids, proteins, ash and water for herring (Clupea harengus), a diatom (Porosira glacialis), orange-footed sea cucumber (Cucumaria frondosa), northern krill (Meganyctiphanes norvegica), pearlside (Maurolicus muelleri), and a mixed mesopelagic batch. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill. All values are given in grams (mean ± SD) per 100 grams wet weight sample.

	C. harengus **(Filet)**	***P. glacialis*** **(whole)**	***C. frondosa*** **(Body wall)**	**Mesopelagic catch**		
				M. norvegica **(whole)**	***M. muelleri*** **(whole)**	**Mixed mesopelagic batch**
Lipids	7.6 ± 0.3 (n = 4)	1.14[1]	1.1 ± 0.0 (n = 3)	2.3 ± 0.0 (n = 4)	12.3 ± 0.7 (n = 4)	8.3 ± 0.4 (n = 4)
Protein	16.7 ± 0.4 (n = 2)	2.6 (n = 1)	7.0 ± 0.1 (n = 2)	14.0 ± 0.3 (n = 2)	12.3[2]	n/a
Ash	1.8 ± 0.0 (n = 3)	6.1 ± 0.1 (n = 3)	3.1 ± 0.3 (n = 4)	3.2 ± 0.0 (n = 2)	2.8 ± 0.4 (n = 2)	2.9 ± 0.1 (n = 2)
Water	71.9 ± 0.2 (n = 3)	86.7 ± 0.2 (n = 3	84.9 ± 0.1 (n = 4)	80.5 ± 0.1 (n = 2)	68.8 ± 0.0 (n = 2)	72.4 ± 0.4 (n = 2)

Number of replicates are given in n = x. N/a represents nutrients that were not applicable and/or available. [1] Adopted from Dalheim et al. (2021). [2] adopted from Institute of Marine Research (n.d.)

3.2 Amino acid composition

In herring, orange-footed sea cucumber, and northern krill, seventeen amino acids were identified, while in the diatom *P. glacialis*, sixteen were identified. The herring had the highest amino acid content, and the highest essential amino acid ratio per amino acid. The diatom had the lowest amino acid content at sixteen percent of the herring, but an essential amino acid ratio at six percentage points lower than the herring. The orange-footed sea cucumber and the northern krill had forty-two percent and fifty-two percent of the amino acid content of herring. But the orange-footed sea cucumber had an essential amino acid ratio at fifteen percentage points lower than the herring, while the northern krill was only four percentage points lower.

Table 2. Amino acid composition in mg (mean ± SD) per gram wet weight herring (Clupea harengus), a diatom (Porosira glacialis), orange-footed sea cucumber (Cucumaria frondosa), northern krill (Meganyctiphanes norvegica), pearlside (Maurolicus muelleri) and a mixed mesopelagic batch. The mixed mesopelagic batch consists of 2/3 of pearlside and 1/3 of northern krill.

	C. harengus **(filet)**	***P. glacialis*** **(whole)**	***C. frondosa*** **(body wall)**	***M. norvegica*** **(whole)**
	(n = 2)	(n = 1)	(n = 2)	(n = 2)
Histidine	4.3 ± 0.0	0.6	1.1 ± 0.0	2.0 ± 0.0
Isoleucine	6.7 ± 0.2	1.0	2.1 ± 0.0	3.3 ± 0.1
Leucine	14.2 ± 0.3	2.2	4.0 ± 0.0	6.7 ± 0.1
Lysine	18.4 ± 0.3	1.6	3.3 ± 0.1	7.5 ± 0.3
Methionine	5.9 ± 0.2	0.7	1.2 ± 0.0	2.6 ± 0.1
Phenylalanine	7.2 ± 0.1	1.5	2.4 ± 0.0	4.4 ± 0.0
Threonine	7.7 ± 0.2	1.2	3.2 ± 0.1	4.0 ± 0.0
Valin	8.0 ± 0.1	1.2	4.3 ± 0.1	3.9 ± 0.1
Total essential amino acids	**72.4 ± 1.4**	**9.9**	**20.0 ± 0.3**	**34.4 ± 0.6**
Arginine	2.7 ± 0.3	1.3	1.5 ± 0.0	6.8 ± 0.9
Alanine	11.3 ± 0.2	2.5	4.3 ± 0.1	6.2 ± 01
Aspartic acid	14.8 ± 0.3	2.7	6.1 ± 0.1	8.2 ± 0.2
Cystine	1.7 ± 0.1	n/a	1.0 ± 0.1	1.0 ± 0.1
Glutamic acid	19.5 ± 0.7	3.6	10.6 ± 0.3	13.6 ± 0.1
Glycine	8.1 ± 0.1	1.6	7.7 ± 0.2	5.7 ± 0.6
Proline	7.0 ± 0.5	1.9	5.7 ± 0.2	4.7 ± 0.9
Serine	7.2 ± 0.1	1.3	4.0 ± 0.1	3.7 ± 0.0
Tyrosine	6.8 ± 0.0	0.8	2.3 ± 0.0	3.2 ± 0.1
Total amino acid	**166.8 ± 3.7**	**26.6**	**70.5 ± 1.4**	**87.6 ± 2.1**
Essential amino acids / Total amino acids	**43.4 %**	**37.2 %**	**28.3 %**	**39.3 %**

**tryptophan is denatured during acid hydrolysis while glutamine and asparagine deaminates during acid hydrolysis and are therefore included in glutamate and asparagine acid. Number of replicates are given in n = x. N/a represent amino acids which where not found.*

3.3 Fatty acid composition

The herring had a high fat content with fatty acids similarly distributed between all fat groups, though it also had the highest amount of unidentified fatty acids. The diatom, in contrast, had a low amount of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA), and consists mostly of polyunsaturated fatty acids (PUFA), representing more than 81 % of the total fatty acid content. The orange-footed sea cucumber had such a low fat content that it become difficult to differentiate within one decimal. Its main fatty acids are the PUFA, eicosapentaenoic acid (C20:5 n-3) and the MUFA palmitoleic acid (C16:1 n-7). The northern krill had a low fatty acid content but is was more equally distributed between the fatty acids. Pearlside had a high fat content, and twice the amount of PUFA as other fat classes. Lastly, the mixed mesopelagic batch, has lipid content between the northern krill and pearlside, though closer to the amounts of the pearlside.

Table 3. Fatty acid composition in gram (mean ± SD) per 100 grams wet weight for herring (Clupea harengus), a diatom (Porosira glacialis), orange-footed sea cucumber (Cucumaria frondosa), northern krill (Meganyctiphanes norvegica), pearlside (Maurolicus muelleri), and a mixed mesopelagic batch. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill.

	***C. harengus* (filet)**	***P. glacialis* (whole) [1]**	***C. frondosa* (body wall)**	**Mesopelagic catch**		
				***M. norvegica* (whole)**	***M. muelleri* (whole)**	**Mixed mesopelagic batch**
	(n = 4)		(n = 3)	(n = 4)	(n = 4)	(n = 4)
Unidentified	**1.7 ± 0.1**		**0.0 ± 0.0**	**0.5 ± 0.1**	**0.1 ± 0.0**	**0.1 ± 0.0**
C12:0			0.0 ± 0.0			
C14:0	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.7 ± 0.2	0.5 ± 0.0
C16:0	0.9 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.4 ± 0.4	1.0 ± 0.1
C18:0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.0
C20:0			0.0 ± 0.0			
Total SFA	**1.5 ± 0.0**	**0.1 ± 0.0**	**0.1 ± 0.0**	**0.5 ± 0.0**	**2.2 ± 0.2**	**1.6 ± 0.0**
C16:1 n-7	0.3 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.3 ± 0.1	0.2 ± 0.0
C18:1 n-7	0.1 ± 0.0		0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
C18:1 n-9	0.6 ± 0.1		0.0 ± 0.0	0.2 ± 0.0	0.6 ± 0.2	0.4 ± 0.0
C20:1 n-9	0.9 ± 0.1		0.0 ± 0.0	0.2 ± 0.0	1.2 ± 0.4	0.8 ± 0.0
C24:1 n-9	0.1 ± 0.0		0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.0
Total MUFA	**1.9 ± 0.0**	**0.1 ± 0.0**	**0.1 ± 0.0**	**0.6 ± 0.0**	**2.2 ± 0.1**	**1.6 ± 0.0**
C16:2 n-4		0.0 ± 0.0				0.0 ± 0.0
C16:3 n-4		0.1 ± 0.0				
C16:4 n-1		0.4 ± 0.0				
C18:2 n-6	0.1 ± 0.0			0.0 ± 0.0	0.2 ± 0.1	0.1 ± 0.0
C18:3 n-3	0.1 ± 0.0			0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0
C18:4 n-3	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.5 ± 0.2	0.4 ± 0.0
C20:4 n-3	0.1 ± 0.0		0.0 ± 0.0	0.4 ± 0.1	2.5 ± 0.8	1.7 ± 0.1
C20:4 n-6			0.0 ± 0.0	0.0 ± 0.0		
C20:5 n-3	0.3 ± 0.1	0.3 ± 0.0	0.2 ± 0.1	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.0
C20:5 n-6						
C22:5 n-3				0.0 ± 0.0		0.0 ± 0.0
C22:6 n-3	0.4 ± 0.1		0.0 ± 0.0	0.3 ± 0.1	0.1 ± 0.2	0.6 ± 0.0
Total PUFA	**1.2 ± 0.0**	**0.9 ± 0.0**	**0.2 ± 0.0**	**0.4 ± 0.0**	**4.2 ± 0.2**	**3.3 ± 0.0**
n-3	**1.0 ± 0.0**	**0.4 ± 0.0**	**0.2 ± 0.0**	**0.2 ± 0.0**	**4.1 ± 0.3**	**3.1 ± 0.0**
n-6	**0.1 ± 0.0**	**0.0 ± 0.0**	**0.0 ± 0.0**	**0.3 ± 0.0**	**0.2 ± 0.1**	**0.1 ± 0.0**
n.6/n-3	**0.01**	**0.0**	**0.1**	**1.7**	**0.0**	**0.0**

SFA: Saturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids. Number of replicates are given in n = x. [1] *Values are adopted from Dalheim* et al. *(2021).*

3.4 Nutrient density scores

Table 4 presents the qualitative and dis-qualitative nutrients used for nutrient density score (NDS) C and G. Herring ensures the daily recommended intake (DRI) of omega – 3 fatty acids for women between age 31 – 60, and closely does the same for men in the same age group per 100 *grams* of herring. Pearlside ensures enough omega – 3 fatty acids and contains almost twice the amount needed for women per 100 *grams*. Pearlside is the only species analyzed that covers the DRI of retinol eq. for both men and women, whereas herring is the only species analysed containing enough vitamin D for both genders per 100 *grams*. The orange-footed sea cucumber and the northern krill contain enough vitamin E for both genders per 100 *grams*, though the orange-footed sea cucumber contains almost triple the DRI. All species except the diatom contain a huge surplus of vitamin B12. The northern krill is the only species close to reaching the daily recommended iodine and calcium content by containing 80 % of the DRI of both nutrients per 100 *grams*. All species that contained selenium, contained enough for the DRI per 100 *grams*, with the northern krill containing twice the amount needed, and the orange-footed sea cucumber containing three times the amount. For the dis-qualitative nutrients, none of the species had a high amount of saturated fatty acids, with the highest found in herring and pearlside (7 – 8 % of the MRI). However, several nutrients were not accessible, particularly for the diatom, and for sodium.

Table 4. Micro- and macronutrients per 100 grams wet weight of herring (Clupea harengus), a diatom (Porosira glacialis), orange-footed sea cucumber (Cucumaria frondosa), northern krill (Meganyctiphanes norvegica), pearlside (Maurolicus muelleri), and a mixed mesopelagic batch. The mixed mesopelagic batch is calculated from 2/3 of the values from pearlside, and 1/3 of northern krill. The nutrients categories is adapted from Hallström et al. (2019).

	C. harengus **(whole)**	***P. glacialis*** **(whole)**	***C. frondosa*** **(body wall)**	***M. norvegica*** **(whole)**	***M. muelleri*** **(whole)**	**Mixed mesopelagic batch (whole)**
	QUALITATIVE NUTRIENTS					
Protein (*grams*)	15.2 [3]	2.4 [6]	6.0 [6]	7.6 [6]	12.3 [5]	10.7
Fibre (*grams*)	0 [3]	n/a	n/a	n/a	n/a	n/a
Omega-3 fatty acids (*grams*)	2.79 [3]	0.4 [8]	0.21 [8]	1.06 [8]	4.08 [8]	3.07
Retinol eq. (*µg*)	6 [3]	n/a	n/a	63.3 [4]	1020 [4]	701.1
Vitamin D (*µg*)	11.5 [3]	n/a	n/a	0 [4]	0 [4]	0
Vitamin E (*mg*)	0.6 [3]	5.186 [7]	28.67 [7]	9.78 [7]	3.93 [7]	5.88
Thiamin (*mg*)	0.04 [3]	0.04 [7]	0.02 [7]	0.03 [7]	0.02 [7]	0.02
Riboflavin (*mg*)	0.3 [3]	0.18 [7]	0.09 [7]	0.21 [7]	0.38 [7]	0.323
Ascorbic acid (*mg*)	0 [3]	n/a	n/a	n/a	n/a	n/a
Niacin equivalents (*mg*)	4 [3]	0.845 [7]	0.59 [7]	3.5 [7]	3.2 [7]	3.3
Vitamin B6 (*mg*)	0.5 [3]	0.067 [7]	0.099 [7]	0.15 [7]	0.15 [7]	0.15
Vitamin B12 (*µg*)	12 [3]	0.46 [7]	8.6 [7]	24 [7]	34 [7]	30.67
Folate (*µg*)	11 [3]	62 [7]	15 [7]	64 [7]	65 [7]	64.67
Phosphorus (*mg*)	290 [3]	n/a	242.7 *[1]	348 [5]	385 [5]	372.67
Iodine (*µg*)	15.9 [3]	n/a	n/a	120 [5]	27 [5]	58
Iron (*mg*)	1 [3]	n/a	3.42 *[1]	1.96 [5]	1.57 [5]	1.7
Calcium (*mg*)	38 [3]	n/a	42.1 *[1]	626 [5]	477 [5]	526.67
Potassium (*grams*)	0.463 [3]	n/a	0.14 *[1]	0.35 [5]	0.242 [5]	0.28
Copper (*mg*)	0 [3]	0.111 [2]	0.07 *[1]	n/a	n/a	n/a
Magnesium (*mg*)	38 [3]	n/a	148.4 *[1]	152 [5]	62.5 [5]	92.33
Selenium (*µg*)	50 [3]	n/a	187.4 *[1]	94 [5]	47 [5]	63.33
Zinc (*mg*)	0.5 [3]	0.927 [2]	3.97 *[1]	1.04 [5]	1.1 [5]	1.08
	DIS-QUALITATIVE NUTRIENTS					
Saturated fatty acids (*grams*)	2.9 [3]	0.1 [8]	0.09 [8]	0.5 [8]	2.19 [8]	1.63
Sodium (*grams*)	0.3 [3]	n/a	n/a	0.456 [5]	0.39 [5]	0.41

**Adopted from whole C. frondosa. N/a represents nutrients that were not applicable and/or available. [1] adopted from Song et al. (2020), [2] is adopted from Hans C. Eilertsen (Professor at UiT, E-mail, January 2021), [3] is adopted from The Norwegian Food Safety Authority (2020), [4] is adopted from Alvheim et al. (2020), [5] is adopted from Institute of Marine Research (n.d.), [6] is adopted from table 1, [7] is adopted from an analysis done by an accredited laboratory at the Institute of marine research in Bergen, [8] is adopted from table 3.*

The nutrient density score (NDS) for men between the age of 31 and 60 is shown in figure 6, and for women between the age of 31 and 60 it is shown in figure 7. Two different nutrient density scores from Hallström *et al.* (2019) were applied, with NDS – G capping the nutrients at 100 % of the DRI (appendix 2), and NDS – C not capping the nutrients. All nutrients included are shown in table 4. A high score represents a more nutritious product and/or a high diversity of essential nutrients.

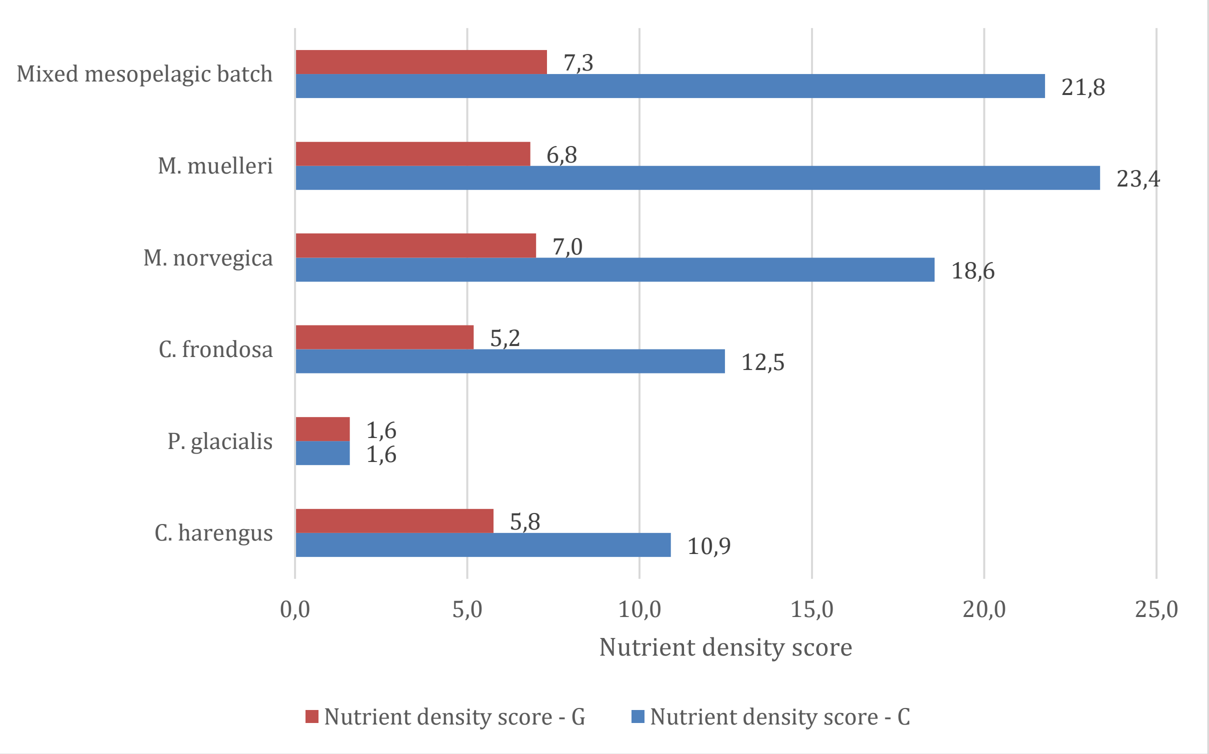

Figure 6. Nutrient density score (NDS) for different species adopted from Hallström et al. (2019). Nutrients scored according to nutrients in table 4, where NDS – G caps nutrients at 100 % of daily recommended intake (appendix 1), and NDS – C do not. The NDS is calculated per 100 grams wet weight of herring (Clupea harengus), pearlside (Maurolicus muelleri), northern krill (Meganyctiphanes norvegica), orange-footed sea cucumber (Cucumaria frondosa), a diatom (Porosira glacialis) and a mesopelagic mix for men between age 31 and 60. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill.

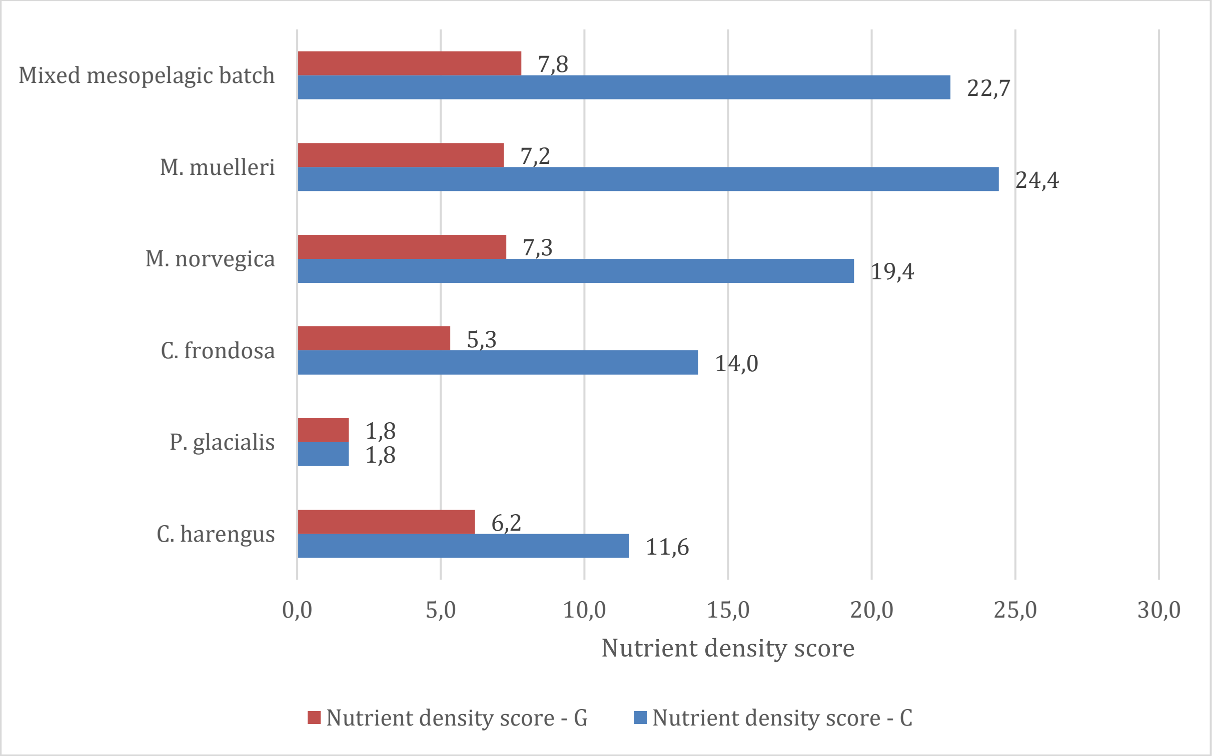

Figure 7. Nutrient density score (NDS) for different species adopted from Hallström et al. (2019). Nutrients scored according to nutrients in table 4, where NDS – G caps nutrients at 100 % of daily recommended intake (appendix 1), and NDS – C do not. The NDS is calculated per 100 grams wet weight of herring (Clupea harengus), pearlside (Maurolicus muelleri), northern krill (Meganyctiphanes norvegica), orange-footed sea cucumber (Cucumaria frondosa), a diatom (Porosira glacialis) and a mesopelagic mix for women between age 31 and 60. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill.

3.5 Carbon dioxide equivalents assessment for aquaculture

The estimated carbon dioxide equivalent emissions for the models of ordinary farmed salmon and farmed salmon feed with pearlside as a novel feedstuff are shown in figure 8. In total, the salmon with novel feedstuff and the ordinary feedstuff emits 10.5 $kg\ CO_2eq./kg$ edible salmon each. The difference between the ordinary salmon and the salmon feed with pearlside is however small and is lost due to rounding to one decimal.

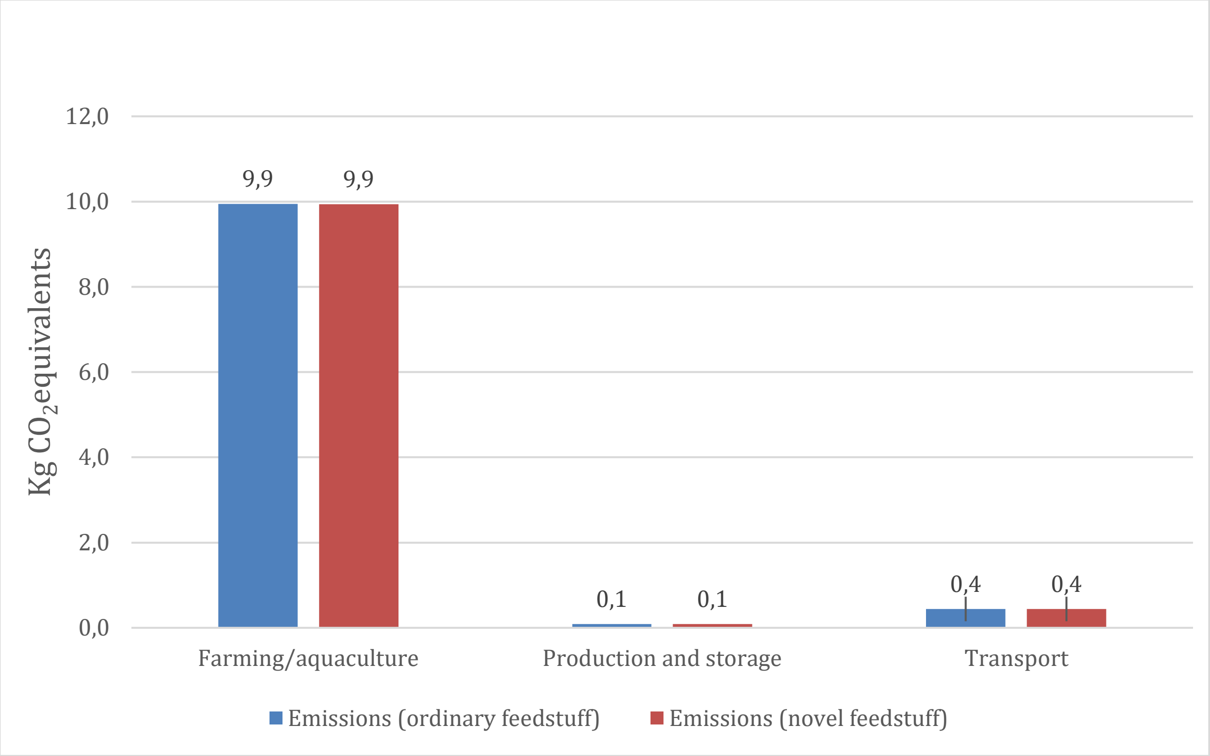

Figure 8. Kg CO_2 equivalents for the farming, production and storage as well as transport of 1 kg edible Atlantic salmon (Salmo salar) produced with the use of a novel feed ingredient and compared with an ordinary feed. The ordinary feed uses pout (Trisopterus esmarkii) and mackerel (Scomber scombrus) as ingredients, while the novel feed uses pearlside (Maurolicus muelleri) as an ingredient. The amount of pearlside, mackerel and pout used in the two feeds are shown in figure 9. The vertical lines in the bars are the max/min values created from different estimates

The proportion of the feed ingredients ensuring the same amount of protein and lipids for both the salmon feed with pearlside and the ordinary salmon feed, with their greenhouse gas (GHG) emissions, are shown in figure 9. The biggest emission source is the pout with a GHG footprint of 7.9 *grams CO2eq./kg* edible salmon. The emissions contribution is 9.4 *grams* CO_2*eq./kg* edible salmon with the use of regular feed ingredients, and 3.4 *grams* CO_2*eq./kg* edible salmon with pearlside as a feed ingredient.

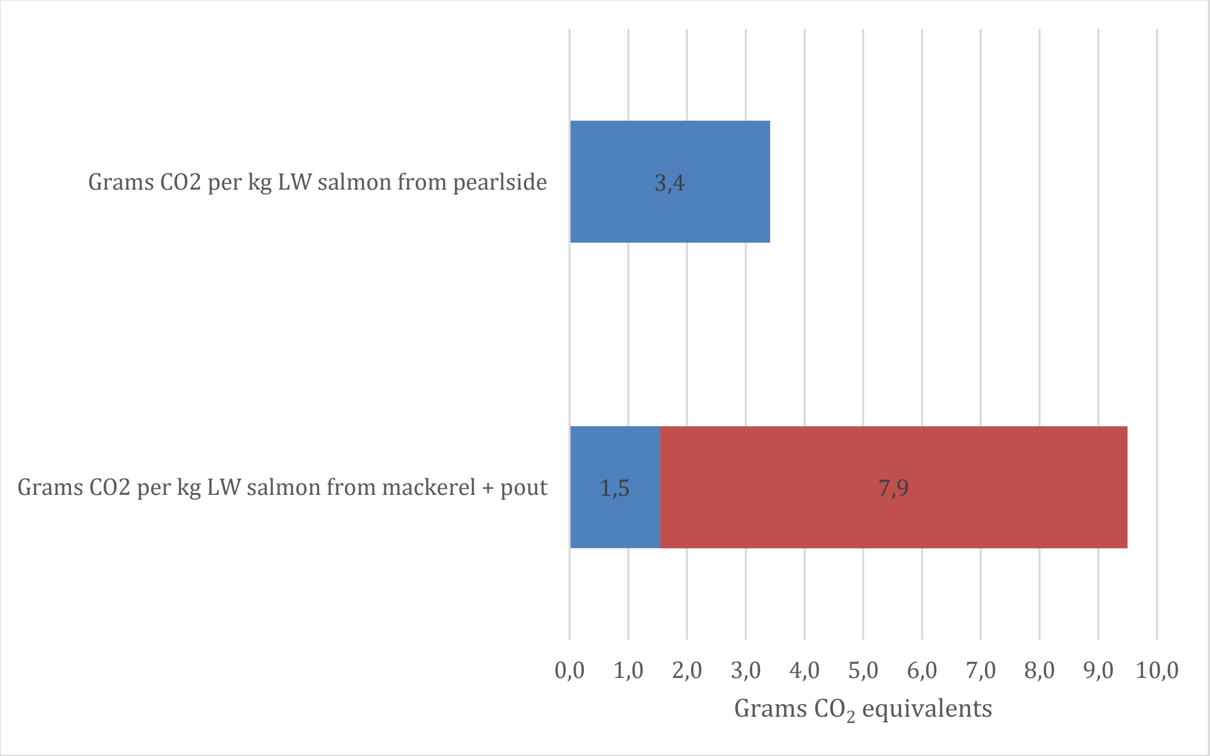

Figure 9. Two estimates of emissions in different salmon (Salmo salar) feed ingredients ensuring the same amount of fats and proteins for the production of one kg live weight salmon.

3.6 Carbon dioxide equivalents assessment for seafood

The estimated CO_2eq. emissions models for herring transported to Gdansk, Poland; herring to Alexandria, Egypt; and orange-footed sea cucumber to Shanghai, China is shown in figure 10. The emissions are highly dependent on the production chains, and only storage have similar emissions across the three production chains. For the herring transported to Alexandria, the emissions are far higher than the herring transported to Gdansk. The emissions from fishery are almost twice as high for the herring to Alexandria, and has almost four times the production emissions, and seven times the transport emissions compared to the herring to Gdansk. Dried orange-footed sea cucumber has similar values as herring exported to Gdansk at all stages, except for fishery, where the orange-footed sea cucumber emits about seven times more. However, the orange-footed sea cucumber is also the only species presented with a notably high maximum and minimum value at the fishery stage

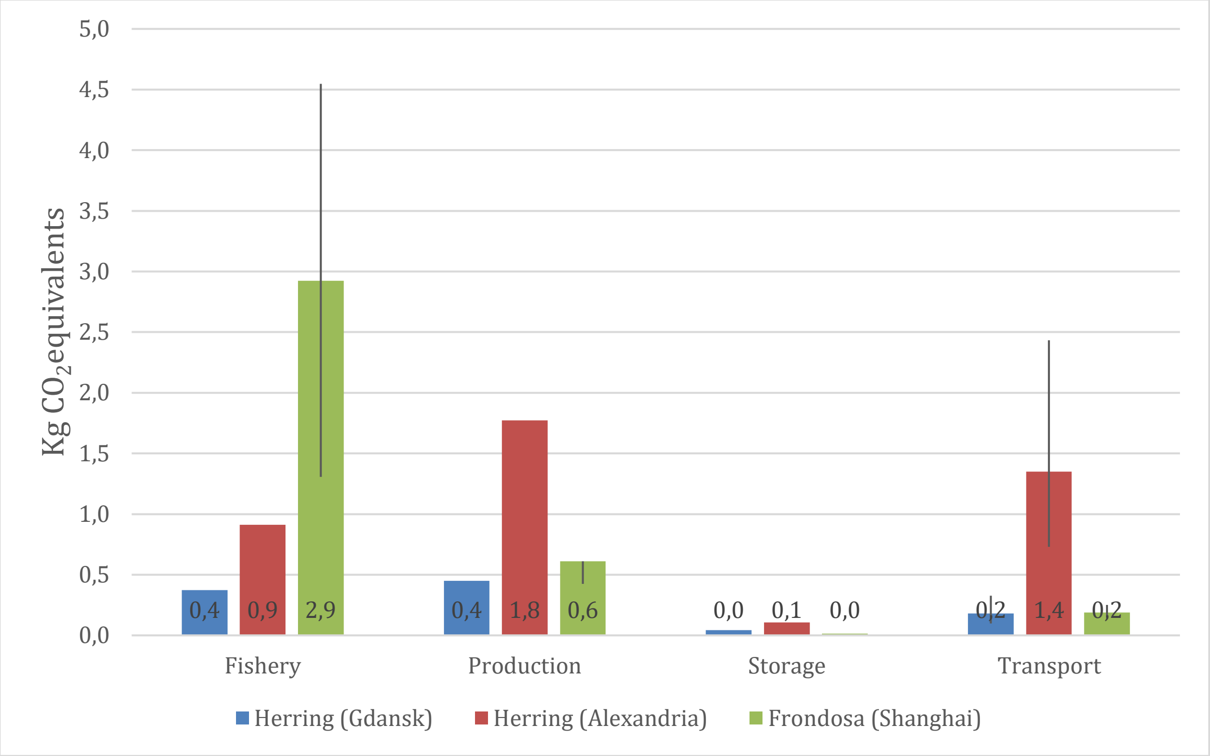

Figure 10. Kg CO_2. equivalents emitted for the production of 1 kg edible herring (Clupea harengus) and orange-footed sea cucumber (Cucumaria frondosa) within cradle to different retail gates. The vertical lines in the bars are max/min values created from different estimates.

The total emissions accumulated from cradle to production gate in Norway, and to retail gate in the international market, for both types of herring, orange-footed sea cucumber, and both types of salmon, is shown in figure 11. For the production chains up until retail gate, the salmon, regardless of feed, have the highest emissions. In contrast, the herring filet exported to Gdansk have the lowest emission. The emissions from orange-footed sea cucumber, is estimated to 3.7 *kg* CO_2*eq./kg* edible product, almost four times the value of the herring filet to Gdansk, but for comparison, it is also one third of the salmon's emissions. All products have slightly lower emissions at production gate compared to at retail gate, except for the herring transported to Alexandria, which has four times the emissions at retail.

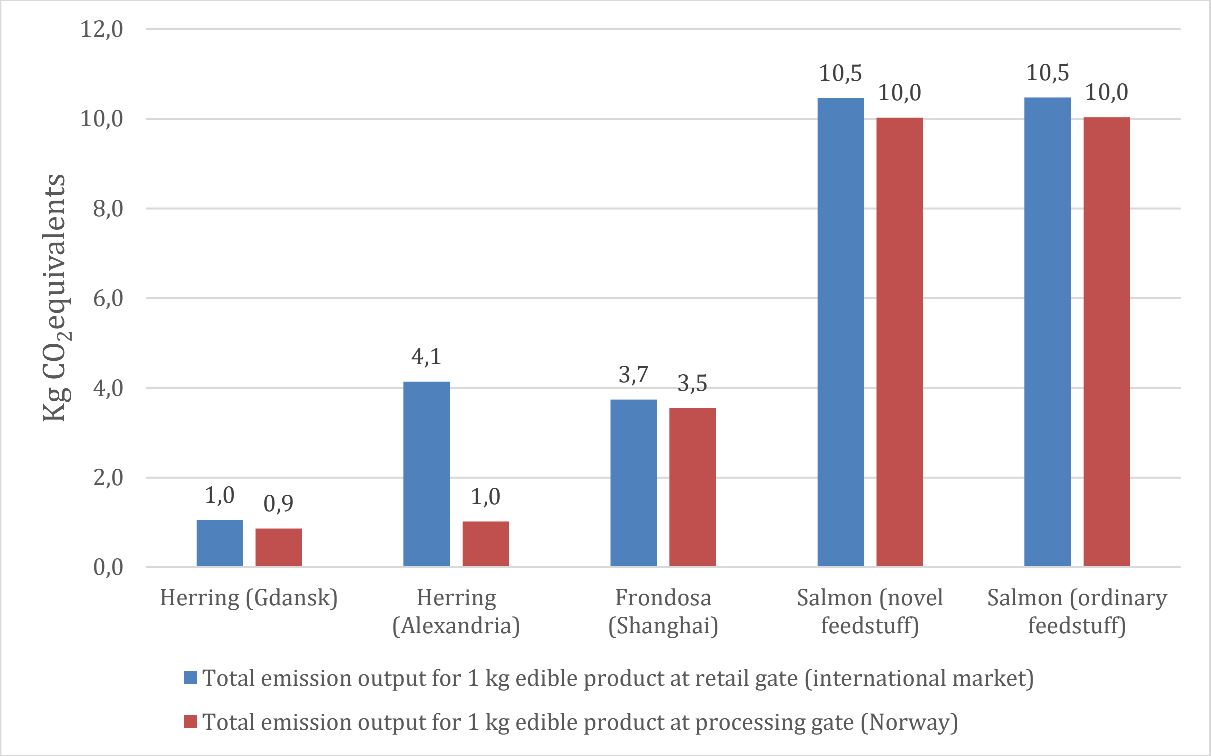

Figure 11. Total amount of CO_2 equivalents emitted for the production of 1 kg edible herring (Clupea harengus), orange-footed sea cucumber (Cucumaria frondosa), and salmon (Salmo salar) throughout the production chain up until production gate (in Norway), and retail gate (in international market)

The emissions for the independent production stages, throughout the production chains for the herring to Alexandria and to Gdansk; the orange-footed sea cucumber; the salmon feed ordinary feed and salmon feed novel feedstuff, transported to Paris is shown in table 5.

Table 5. Emissions (kg CO_2 equivalents) released in the production of 1 kg edible product within cradle to retail gate for herring (Clupea harengus) to Gdansk (Poland) and Alexandria (Egypt), orange-footed sea cucumber (Cucumaria frondosa) to Shanghai (The People's Republic of China), and salmon (Salmo salar) with two different feed scenarios to Paris (France).

	Fishery/farming	**Production**	**Storage**	**Transport**	**Total**
Herring (Gdansk)	0.4	0.4	0.0	0.2	**1.0**
Herring (Alexandria)	0.9	1.8	0.1	1.4	**4.1**
Orange-footed sea cucumber (Shanghai)	2.9	0.6	0.0	0.2	**3.7**
Salmon (ordinary feedstuff, Paris)	9.9	0.1		0.4	**10.5**
Salmon (novel feedstuff, Paris)	9.9	0.1		0.4	**10.5**

3.7 Carbon dioxide equivalents and nutrient density score comparison

Figure 12 summarises the emissions and the nutrient density scores for herring and orange-footed sea cucumber for both men and women age 31 – 60 and compares it with the emissions estimate for whole herring-, herring filet-, and orange-footed sea cucumber sold in Norway. Nutrient scores are presented per 100 *grams* wet weight and emissions are presented per 100 *grams* edible product. A high score represents a more nutritious product and/or a high diversity of essential nutrients.

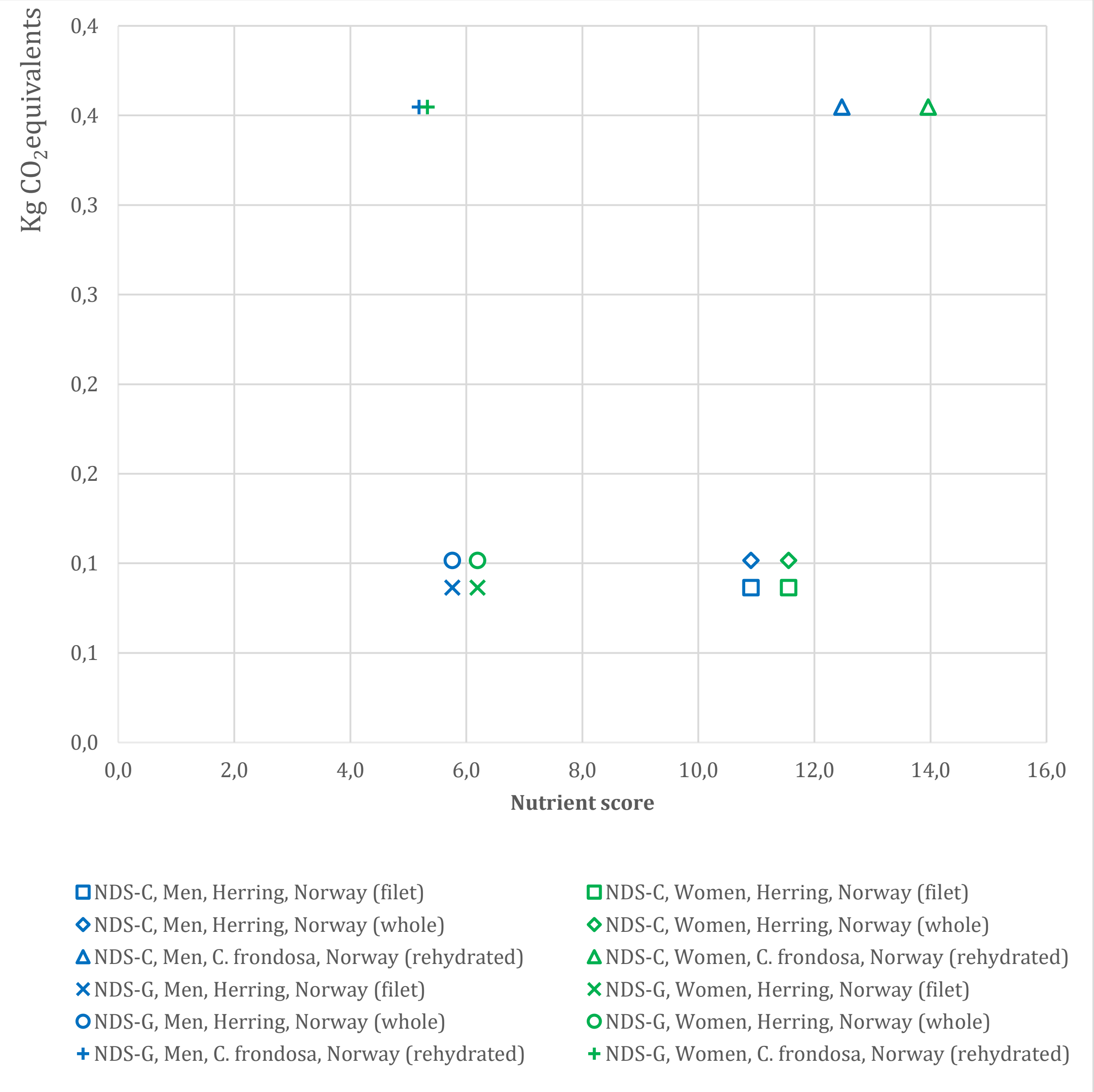

Figure 12. Nutrient density score (NDS) C and G for men and women between age 31 – 60, adapted from Hallström et al. (2019) and compared with the CO_2eq emissions for herring (Clupea harengus) filet, whole herring, and orange-footed sea cucumber (Cucumaria frondosa) at production gate. NDS – C scores nutrients according to values shown in table 4, while NDS – G utilises the same nutrients, but caps the nutrients at 100 % of the daily recommended intake, shown in appendix 2. Nutrient density score is calculated per 100 grams wet weight sample while the CO_2eq emissions are calculated per 100 grams edible product.

4 Discussion

4.1 Nutrients

The nutritional values for all the species analysed, varied, giving the species different fields where they can be applied as food, or food related resources. Particularly the herring and the pearlside, with their high content of lipids and protein, provide a great source for securing dietary energy, omega - 3 fatty acids, and essential amino acids. The orange-footed sea cucumber and the norther krill on the other side, have lower contents of energy-providing nutrients (proteins and lipids). These species, are nonetheless, medium to high in micronutrients, which makes them more suitable for populations with excessive net energy intake and micronutrient deficiency. The diatom scores lower on energy-providing nutrients, is high in polyunsaturated fatty acids (PUFA), and has a micronutrient composition that is lower than the other analysed species. Its high content of ash however, is most likely from the silica-based cell walls (Svenning *et al.*, 2020). The mesopelagic mix consists of a higher degree of pearlside than northern krill, which explains why its nutrients is more similar to the pearlside. The mesopelagic mix do however score better than the other species analysed on micronutrients, when the nutrients are capped at 100 % of the daily recommended intake (DRI), meaning the krill creates a wider nutrient diversity in the mix.

Across all the marine species, the nutrient score is slightly higher for women. NDS – C scores almost triple the amount compared with NDS – G in all species except for the diatom, where the scores are the same. The species with the highest nutritional contribution without capping, is the pearlside, with the diatom scoring the lowest. For the nutrient scores with capping, the mixed mesopelagic batch scores the best, while the diatom scores the lowest. The capping effects the pearlside, the northern krill, and the mesopelagic batch the most, and the nutrient scores for these species, are far closer to each other according to NDS – G compared to NDS – C. This indicates that several of the species have a nutrient composition far higher than the DRI for certain nutrients.

The nutrient most affected by the capping (NDS – G) was vitamin B12. The vitamin B12 content was between four and seventeen times the daily recommended intake (DRI) in the species analysed. However, the nutritional value of high content of vitamin B12 is questionable even though it is a vital part of erythropoiesis. But since vitamin B12 is a water-soluble vitamin, increased consumption of this vitamin will lead to an increased excretion of the vitamin due to the low storage potential in the body (Widmaier *et al.*, 2016).

As noted in chapter 1.3, the main micronutrients lacking in the Norwegian diet are vitamin D, folate, iron, iodine, alongside, the diet should substitute saturated fatty acids with polyunsaturated fatty acids. Though, as shown in table 4, neither vitamin D, iron, or iodine were analysed for the diatom, nor were vitamin D and iodine analysed for the orange-footed sea cucumber. So, by consuming a portion of 100 *grams,* herring will provide more than 100 % of the recommended vitamin D and omega – 3; northern krill will provide 80 % of the recommended iodine; pearlside will provide more than 100 % of the recommended omega – 3; and the mesopelagic mix will provide 40 % of the recommended iodine and more than 100 % of the recommended omega – 3. It is therefore safe to say that these species do have the potential for supplementing the Norwegian diet to avoid malnutrition. Fatty fish species is already a known source of vitamin D and omega – 3 (National Council for Nutrients, 2018; 2017), though, the content of iodine in the northern krill could be of relevance, being four times the content of commercially available shrimp (The Norwegian Food Safety Authority, 2020). This is something that could be further highlighted by using another of the nutrient density scores by Hallström *et al.* (2019) like NDS - F, which weights the nutrients according to the nutrient deficiencies and surplus in the population. Lastly, it should be added that diatoms have shown potential for ascorbic acid (Del Mondo *et al.*, 2020; Brown and Miller, 1992), potentially increasing its nutrient score.

This work, analyses, and literature search could not provide all the nutrients needed for the nutrient density scores, resulting in a partly deficient representation of the micronutrients for some of the species. The diatom lacks eleven qualitative- and one dis-qualitative nutrients, the orange-footed sea cucumber lacks five qualitative- and one dis-qualitative nutrient, and the pearlside and northern krill lack three qualitative nutrients. This results in a lower nutrient density score (NDS) in the diatom, compared to the true NDS if all of its nutrients were included. The NDS for the same species, but including only the nutrient data available for all species, is shown in table 6 and illustrated in figure 13 for men, and figure 14 for women. Compared with figure 6 and 7, this results in halving the NDS-G for all species except the diatom, while lowering the NDS-C for all species.

Table 6. Micro- and macronutrients available in literature and analyses for all species, per 100 grams wet weight of herring (Clupea harengus), a diatom (Porosira glacialis), orange-footed sea cucumber (Cucumaria frondosa), northern krill (Meganyctiphanes norvegica), pearlside (Maurolicus muelleri), and a mixed mesopelagic batch. The mixed mesopelagic batch is calculated from 2/3 of the values from pearlside, and 1/3 of northern krill. The nutrients categories is adapted from Hallström et al. (2019).

	C. harengus **(whole)**	***P. glacialis*** **(whole)**	***C. frondosa*** **(Body/whole)**	***M. norvegica*** **(whole)**	***M. muelleri*** **(whole)**	**Mixed mesopelagic batch (whole)**
	QUALITATIVE NUTRIENTS					
Protein (*grams*)	15.2 [3]	2.6 [6]	7.0 [6]	14.0 [6]	12.3 [4]	12.9
Omega-3 fatty acids (*grams*)	2.79 [3]	0.4 [7]	0.21 [7]	1.06 [7]	4.08 [7]	3.1
Vitamin E (*mg*)	0.6 [3]	5.186 [5]	28.67 [5]	9.78 [5]	3.93 [5]	5.9
Thiamin (*mg*)	0.04 [3]	0.04 [5]	0.02 [5]	0.03 [5]	0.02 [5]	0.02
Riboflavin (*mg*)	0.3 [3]	0.18 [5]	0.09 [5]	0.21 [5]	0.38 [5]	0.32
Niacin equivalents (*mg*)	4 [3]	0.845 [5]	0.59 [5]	3.5 [5]	3.2 [5]	3.3
Vitamin B6 (*mg*)	0.5 [3]	0.067 [5]	0.099 [5]	0.15 [5]	0.15 [5]	0.15
Vitamin B12 (*µg*)	12 [3]	0.46 [5]	8.6 [5]	24 [5]	34 [5]	30.67
Folate (*µg*)	11 [3]	62 [5]	15 [5]	64 [5]	65 [5]	64.67
Zinc (*mg*)	0.5 [3]	0.927 [2]	3.97 [1]	1.04 [4]	1.1 [4]	1.1
	DIS-QUALITATIVE NUTRIENTS					
Saturated fatty acids (*grams*)	2.9 [3]	0.1 [7]	0.09 [7]	0.5 [7]	2.19 [7]	1.6

[1] Adopted from Song et al. (2020), [2] is adopted from Hans C. Eilertsen (Professor at UiT, E-mail, January 2021), [3] is adopted from The Norwegian Food Safety Authority (2020), [4] is adopted from Institute of Marine Research (n.d.), [5] is adopted from an analysis done by an accredited laboratory at the Institute of marine research in Bergen, and [6] is adopted from table 1, [7] is adopted from table 3.

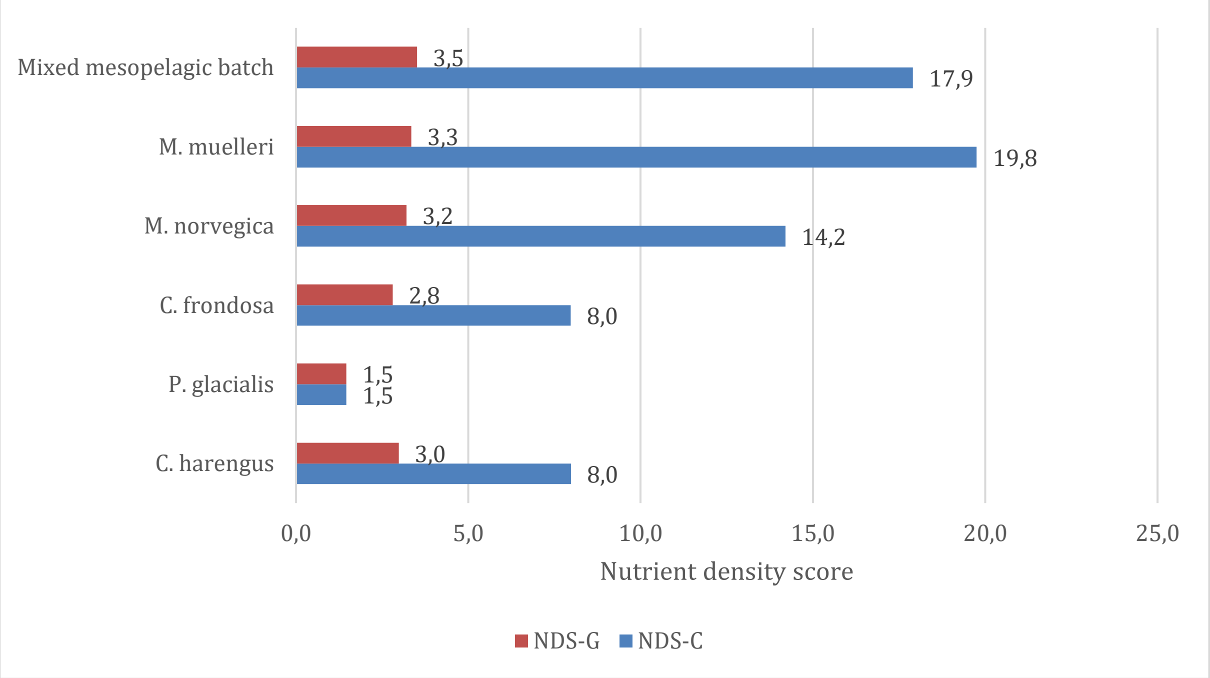

Figure 13. Nutrient density score (NDS) for different species adopted from Hallström et al. (2019). Nutrients scored according to nutrients in table 6, where NDS – G caps nutrients at 100 % of daily recommended intake (appendix 1), and NDS – C do not. The NDS is calculated per 100 grams wet weight of herring (Clupea harengus), pearlside (Maurolicus muelleri), northern krill (Meganyctiphanes norvegica), orange-footed sea cucumber (Cucumaria frondosa), a diatom (Porosira glacialis) and a mesopelagic mix for men between age 31 and 60. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill.

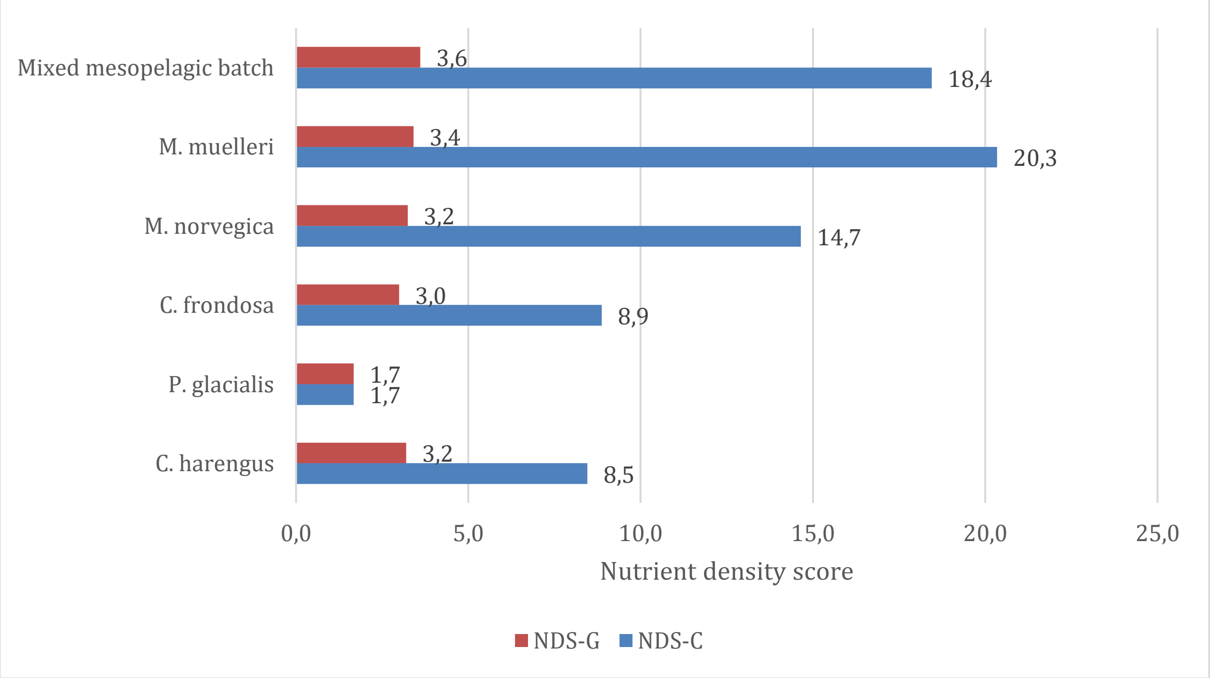

Figure 14. Nutrient density score (NDS) for different species adopted from Hallström et al. (2019). Nutrients scored according to nutrients in table 6, where NDS – G caps nutrients at 100 % of daily recommended intake (appendix 1), and NDS – C do not. The NDS is calculated per 100 grams wet weight of herring (Clupea harengus), pearlside (Maurolicus muelleri), northern krill (Meganyctiphanes norvegica), orange-footed sea cucumber (Cucumaria frondosa), a diatom (Porosira glacialis) and a mesopelagic mix for women between age 31 and 60. The mixed mesopelagic batch consists of 2/3 of pearlside, and 1/3 of northern krill.

As a direct food source, the orange-footed sea cucumber and the herring already have, as pointed out in chapter 2.2.1 and 2.2.2, existing markets for human consumption. The pearlside and the northern krill on the other hand, have no existing market for human consumption. But some speculations have been done by The Norwegian Institute of Marine Research, if species like pearlside could be used along the lines of sardines. It is nonetheless a concern that the pearlside contains a fair amount of wax esters, meaning the species should not be consumed in too high volumes (Dahl, 2018). Pearlside might however prove more beneficial as an ingredient in salmon feed with its high fat content. In the latest decades, salmon feed has increased its use of terrestrial fatty acids due to accessibility and price, correspondingly reducing the salmon's composition of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Aas, Ytrestøyl and Åsgård, 2019; Sprague, Dick and Tocher, 2016). However, EPA and DHA are vital for salmon- and human health (Nofima, 2017; Sprague, Dick and Tocher, 2016), meaning the addition of pearlside as a feed ingredient might be valuable. Though, the potential of pearlside as a protein source must also be kept in mind, since too low content of fishmeal in salmon feed has shown to reduce growth and feed efficiency (Waagbø *et al.*, 2013)

In a broader scale, The United Nations have decided that *Zero hunger* and *Good health and well-being*, will be two of their sustainability goals. This requires ending all forms of malnutrition and providing a nutritional diverse and healthy diet (United Nations, 2015a). For many developing countries protein malnutrition is among the most severe health problems due to diets mostly consisting of cereals and mono carbohydrate diets (Bessada, Barreira and Oliveira, 2019). A purely plant-based diet can also carry other consequential nutrient deficiencies, particularly if the overall diet quality is low and lacks nutrient-rich plant-based foods. Here, young children and pregnant or lactating women are at even higher risk due to their elevated nutrient requirements. Therefore, the use of aquatic animals as an affordable source of protein and micronutrients is already widely suggested (FAO *et al.*, 2020). However, the use of mesopelagic fish in contrast to other fish species, could fulfill a bigger proportion of the nutritional requirement due to its high nutrient density, as shown in this thesis, but also in other literature (Nordhagen *et al.*, 2020)

4.2 Carbon dioxide emissions

The carbon dioxide equivalent assessment was based on simple calculations done with accessible data from several external sources. Several software programs popular in Europe like Simapro, Gaba, and OpenLCA were investigated (Fazio, Kusche and Zampori, 2016), though, these programs proved to have several challenges making them unsuitable for this thesis. First, they were too costly. Second, in a university context, they might be more suited as a learning software and further used as an integrated part of a thesis, as all required a fair amount of know-how to be used in an optimal way. Thirdly, some of them also required the use of expensive third-party databases like Ecoinvent, as seen in Winther *et al.* (2020). Lastly, some of the databases also gave results far wider than the scope of this thesis, by providing data for acidification, depletion of abiotic resources, ozone layer depletion, and more, alongside the greenhouse gas (GHG) emissions, as shown in Ruiz-Salmón *et al.* (2021) while only GHG emissions were within the scope of this thesis. Thus, the calculations were based on the ISO 14040 and 14044 guidelines presented in Winther *et al.* (2009) and Winther *et al.* (2020). The ISO standards provide an important framework for life cycle assessments (European Commission, n.d.), and it was chosen to mimic reports where these standards were used as a baseline of their analysis.

The difference in emissions for salmon feed with pearlside as an ingredient, and ordinary salmon feed, is very little. The main reason for this is the low proportion of pout and mackerel in the feed, making the emissions of the pearlside lost in the bigger picture. A potential bigger impact could be achieved by substituting additional marine species, or by substituting some of the plant-based protein. Particularly soybean could be of interest, which constitutes 20.6 % of the salmon feed, and emits 6.01 $kg\ CO_2eq/kg$ soy bean (Winther *et al.*, 2020).

Herring to Gdansk have the lowest emissions of the species analysed, while herring to Alexandria have four times that emissions. This is the result of several factors, but the major culprit is the lack of utilization of by-products. For one *kg* of edible herring 2.8 *kg* of whole herring is required, however, within Norwegian production, the utilization of by-products is well documented to be used in other products, while the production in Egypt do not. This results in the total emission for the Norwegian production being shared between the by-products and the edible product, making the edible product representing a lower emission value. This, assumed full utilization of by-products, also explaining why the herring to Gdansk had a lower fishery emission than the herring to Alexandria, even if the same amount of fish were caught in both scenarios. This is further highlighted when the herring filet to Gdansk and the whole herring to Alexandria have similar emissions at the production gate, even though the herring filet required more energy through processing. But, as noted by Winther *et al.* (2020), the lack of robust data or documentation of utilisation of by-products internationally, is detrimental when comparing products processed abroad. The emission at the production and transport stage, however, are influenced by several other factors such as: The need to transport whole herring compared to filleted herring, and the carbon footprint of the electricity used.

The orange-footed sea cucumber has emissions similar to the herring to Gdansk on most stages, however it has the largest emission outlet during fishery of all species analysed. This results in the orange-footed sea cucumber having four times the emissions of the herring to Gdansk. Though, as the fishery emission is calculated based on data for trawling and gutting of fish, this value may be uncertain. However, bottom trawl is the most emitting fishing equipment found in Winther *et al.* (2009), and recent literature points out that trawls and dredgers can cause re-mineralizing of sedimentary carbon to CO_2, causing greater harm than previously anticipated (Sala *et al.*, 2021). So, the use of alternative fishing methods, if possible, should be considered. The production emissions for the orange-footed sea cucumber are comparable to the herring to Gdansk, and by the use of the drying equipment of Algetun AS instead of Munters, the emissions are close to identical. However, Munters equipment is more common (Ragnvald Maartmann-Moe, CEO at Algetun AS, E-mail, November 2020), and its estimated electricity requirements closer to relatable processing for dried cod (Muir, 2015), hence, Munters values were found more realistic. Lastly, the emission related to the transport phase of the orange-footed sea cucumber is among the lowest for all products analysed, even with it having the longest transport distance. This is based upon the orange-footed sea cucumber being transported as a dried product, and by decreasing in volume, it has a higher edible ratio per *kg* transported. But transport is, in general, representing a low proportion of the total emission. The exemption for this is when particular circumstances occurs, as with seafood being transported to The Peoples Republic of China and back Norway, or with air fright (Winther *et al.*, 2020; Winther *et al.*, 2009).

Compared to other analyses, the results in this thesis show some distinctions to Winther *et al.* (2020), except for the herring filet sold to Gdansk. The major differences are due to Winther *et al.* (2020) applies a by-product utilization which could not be replicated in this thesis. But, as shown in table 7, if the analysis applies the same by-product utilization as Winther *et al*. (2020), both the salmon feed with pearlside, and the whole herring, becomes more comparable with the results from Wither *et al.* (2020). Table 7 also shows how the herring to Gdansk, herring to Alexandria, the orange-footed sea cucumber, and the salmon with novel, and regular feedstuffs compares to regular seafood products and terrestrial products on GHG emissions per *kg* edible product, per 100 *grams* protein, and per 1000 *kcal*.

Table 7. Emission (Kg CO_2eq.) per kg edible product, per 100 grams protein, and per 1000 kcal for herring (Clupea harengus), orange-footed sea cucumber (Cucumaria frondosa), farmed salmon (Salmo salar), and common terrestrial protein sources.

	Kg **CO_2*eq.* per *kg* edible product**	***Kg*** **CO_2*eq.* per 100 *grams* protein**	***Kg*** **CO_2*eq.* per 1000 *kcal***
Frozen herring filet transported by sea to Gdansk. 0 % by-product utilized in the market.	1.1	0.8 [5]	0.06 [4]
Whole frozen herring transported by sea to Alexandria. 0 % by-product utilized in the market.	4.1	2.9 [5]	0.22 [4]
Dried orange-footed sea cucumber transported on sea to Shanghai. 0 % by-product utilized in the market.	3.7	6.2 [5]	n/a
Salmon with pearlside as a feed ingredient, transported to Paris by truck. 0 % by-product utilized in the market.	10.5	5.3 [4]	0.47 [4]
Salmon with ordinary feed transported to Paris by truck. 0 % by-product utilized in the market.	10.5	5.3 [4]	0.47 [4]
Fresh H&G salmon, transported to Paris by road and ferry. 80% by-product utilized in the market [1].	6.5	3.3 [4]	0.29 [4]
Fresh, head off cod, transported to Paris by road and ferry. 70% by-product utilized in the market [1].	1.8	1.0 [4]	0.22 [4]
Frozen, round herring, transported to Kiev by road and ship. 70% by-product utilized in the market [1].	1.1	0.8 [5]	0.06 [4]
Whole frozen herring transported by sea to Alexandria. 70 % by-product utilized in the market as done by Winther *et al.* (2020).	2.3	1.6 [5]	0.12 [4]
Salmon with pearlside as a feed ingredient transported to Paris by truck. 80 % by-product utilized in the market as done by Winther et al. (2020).	6.7	3.4 [4]	0.30 [4]
Norwegian pork (inside round, raw) within cradle to retail [2]	5.9	2.7 [4]	0.57 [4]
Norwegian chicken (filet, no skin, raw) within cradle to retail [2]	2.8	1.2 [4]	0.25 [4]
West European beef (inside round, raw) within cradle to retail [2]	28.3	12.6 [4]	2.69 [4]
Norwegian wheat (wheat flour, sieved) [3]	0.88	0.9 [4] *	0.05 [4]
Norwegian potatoes (autumn potato, raw) [3]	0.3	1.5 [4] *	0.3 [4]

**Protein quality of vegetables differ from animal protein. The abbreviation n/a represents nutrients that were not applicable and/or available. Where several values are given for the same species, the average is used. Conversion to kg edible is done by using a yield factor of 75%, 62% and 76% for beef, pork and chicken, respectively as done by Hallström, Röös and Börjesson (2014). [1] Values from chapter 1.5.3, [2] Values from chapter 1.5.1 Meat diets, [3] Values from chapter 1.5.2. Where several values are given for the same vegetable, the average is used. [4] Protein and kcal values are adopted from The Norwegian Food Safety Authority (2020). [5] Protein values adopted from table 2.*

To keep in line with the Paris convention ambition of cutting GHG emissions, Norway has put in place *Klimakur 2030*, as a guideline for cutting emissions in the non-quota sector. As shown in chapter 1.1, the Norwegian diet consists of a high degree of meat and meat products, however, a substitution of red meat with fish/marine products appear to be beneficial for keeping macronutrient adequacy while reducing carbon emissions. Similar claims has also been proposed by The Norwegian Environment Agency *et al.* (2020) which has pointed out that substitution of red meat to plant-based and fish-based diets can reduce the total emissions by almost 3 million ton CO_2eq. Though, some seafood alternatives show bigger potential in reducing climate emissions than others. Herring for one, emitting the lowest emissions per *kg* edible product, per 100 *grams* protein, and per 1000 *kcal*. Though, cod shows similar emissions per 100 *grams* protein. Salmon with 70 % by-product utilized in the market emits second to worst per *kg* edible, but emits closer to chicken and cod per 1000 *kcal*. Though, farmed salmon could emit far less with changes in the salmon feed as shown in this work, and in Winther *et al.* (2020). Alongside, changes in salmon diet to include more marine feed ingredients, could alleviate land use constraints relative to other terrestrial animal proteins (World Resources Institute *et al.*, 2019). When it comes to protein, the orange-footed sea cucumber should be avoided as a source of protein, since it emits second to most per 100 *grams* protein, only beaten by beef.

Some of the species analysed are novel species with little, or no existing commercial fishery. Therefore, it is valuable to pinpoint which strengths and weaknesses the independent species provides so the different benefits and weaknesses can be promoted to create a healthy and sustainable diet. At the same time, it may create economic advantages with the development of the European Union taxonomy system, which seeks to enable sustainable investments (European Union Technical Expert Group on Sustainable Finance, 2020). This could greatly benefit novel resources which show particular advantages with low emissions and high nutrient content, like the pearlside appeared to do in this thesis.

4.3 Future work

Time was allocated to construct a life cycle assessment (LCA) and estimate greenhouse gas (GHG) emission for the diatom *P. glacialis*. This was however cut short due to time constraints. The diatom does however show potential as they are distinguished by their capability to synthesize long-chained polyunsaturated fatty acids like eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Svenning *et al.*, 2019), nutrients sought after for salmon feed (Sprague, Dick and Tocher, 2016). Algae-based oils have already been recommended as a substitute for terrestrial vegetable oils in aquafeed if the energy demand of the algae production is reduced (Ghamkhar and Hicks, 2020). Energy consumption and the use of “wasted” energy are properties to be optimized in the diatom *P. glacialis* cultivation in the Finnfjord project at The Arctic University of Tromsø. The use of the diatom for direct human consumption, however, is uncertain. Adaption of novel food resources is heavily regulated (Official Journal of the European Union, 2015), and currently, only a limited number of microalgae species are approved under the European regulations for food use (Enzing *et al.*, 2014).

The northern krill (*M. norvegica*) is another species not investigated with an LCA in this thesis, but is likely to have properties worth analysing. The krill *Euphausia superba* is already used as an ingredient in ordinary salmon feed (Winther *et al.,* 2020). However, Winther *et al.* (2020) emphasis how micro-ingredients disproportionally contributes to a larger GHG footprint of salmon feed, with pigmentation representing a fair proportion of this. A common source of pigments used in salmon feed is the carotenoid astaxanthin, an antioxidant found in northern krill (Solberg, 2006). Thus, the addition of northern krill may provide the needed pigmentation, and thus reduce the GHG footprint of the micronutrients used in salmon feed. A second commercial application of the northern krill is dietary supplements, just as done with *E. superba*, since krill contain high levels of essential marine omega – 3 fatty acids, choline, phospholipids, and as mentioned, astaxanthin (Nash, Schlabach and Nichols, 2014). On the other hand, since the northern krill had lower protein and lipid content, alongside a lower catch rate than the pearlside (appendix 1), its utility as a direct protein and lipid source is likely lower than pearlside.

A tertiary field for future work is the composition of the mesopelagic trawls, since several hauls contained a wide diversity of species. In this thesis, a prerequisite for the LCA was that the mesopelagic species could be harvested separately and used pearlside as a novel feed ingredient. The use of a catch of pearlside may be plausible since haul 1, 9, 11, and 12 (appendix

1), consisted of more than 95 % pearlside, values also achieved by Grimaldo *et al.* (2020). On the other hand, if the species prove difficult to harvest separately, the contents of marine lipids and proteins in an unsorted haul, with pearlside as the main species, is nonetheless comparable to nutrient values found in other commercial species (Grimaldo *et al.*, 2020). If the haul favors other species like in haul 3, where northern krill represent 74 % of the biomass, the nutrition potential of such a mix for salmon feed, needs to be considered.

The emissions of the mesopelagic fishery should also be further analysed. In this thesis, emission data for the mesopelagic fishery was adopted from a krill fishery, and correspondingly, with its fuel efficiency. However, Grimaldo *et al.* (2020) report catches of 0 – 3 000 *kg* mesopelagic species in 15 – 120 *minutes*, while Øystein Lie (Senior Advisor at Liegruppen AS, E-mail, November 2020) reports an average of six hours to achieve hauls between 10 000 – 40 000 *kg*. A krill fishery can achieve catch rates of 100 – 400 *tonnes* per day, though catch rates as high as 800 *tonnes* per day have been reported (Nicol, Foster and Kawaguchi, 2012). The Norwegian Institute of Marine Research has proposed that one of the reasons mesopelagic fishery has not become more popular, is its struggle to attain economic viability (Fagerbakke, 2020). Further knowledge on efficiency in the fishery and harvest of mesopelagic species is thus warranted.

4.4 Limitations

As noted in chapter 2.2, the life cycle assessments used in this thesis have not been revised by an external expert in accordance with the ISO standard for LCA’s of public product comparisons (Winther *et al.*, 2009). Thus, the results should only be used as guidance in further work.

The emissions from the reduction of fish to fishmeal and fish oil were not included in the LCA for the pearlside, which artificially lowers its emissions as an ingredient in feed. When substituting the protein and oil amounts in salmon feed by including pearlside instead of mackerel and pout, it required an uneven amount of pearlside for protein and oil. This led to an overproduction of oil. This oil surplus was not included in further calculations, though, by including it, it would reduce the total emissions for pearlside as an ingredient.

In Winther *et al.* (2020), waste handling was estimated with data from Ecoinvest. However, as this database was not accessible, and thus could not be replicated, the total emission of the novel species become lower in comparison.

For the nutrient analysis, several limitations need attention. First, the amino acid analysis for the pearlside resulted in unrealistic values. The content of protein where thus substituted with values from literature. The amino acid analysis of one of the replicates of the diatom contained an elevated amount of ammonia, and no content of tyrosine or histidine. Thus, it was decided to present data only for one replicate. The extraction of lipids from the diatom was challenging and resulted in a huge variation between replicates. The lipid and fatty acid content of the diatom was therefore substituted with values from literature. Lastly, the internal standard content in the fatty acid analysis of the orange-footed sea cucumber was slightly higher than recommended, potentially effecting its results.

The nutritional density score (NDS) do not reflect the possible fluctuations of specific nutrients. Example, fat content will vary depending on season, while iodine will vary depending on grazing area (Grimaldo *et al.*, 2020; Nerhus *et al.*, 2018).

5 Conclusion

The need for alternative nutritious food sources with low emissions of greenhouse gases (GHG) is pressing. In this thesis orange-footed sea cucumber (*Cucumaria frondosa*), the diatom *Porosira glacialis*, northern krill (*Meganyctiphanes norvegica*), pearlside (*Maurolicus muelleri*), and Atlantic herring (*Clupea harengus*) was analysed, estimated for CO_2eq. emissions, and ranked with nutrient density scores (NDS) with and without capping at 100 % of the daily recommended intake (DRI). The orange-footed sea cucumber is low in energy-providing nutrients, scored mediocre on micro- and macronutrients compared to the other species but scored lower when the nutrients were capped at 100 % of the DRI. The emissions were mediocre, both compared to the other species analysed, and when compared with other protein sources such as commercially available seafood species and terrestrial animals. The diatom requires further analysis but contains a high proportion of marine long chained polyunsaturated fatty acids. The northern krill was mediocre in energy-providing nutrients, scored high on micro- and macronutrients compared to the other species, but mediocre when the nutrients were capped. The pearlside was high in energy-providing nutrients, scored high on micro- and macronutrients compared to the other species and mediocre when the nutrients were capped. The emissions of the pearlside were low compared to standard marine ingredients used in salmon feed. The herring was high in energy-providing nutrients, scored mediocre on micro- and macronutrients compared to the other species and lower when the nutrients were capped. The emissions of the herring are heavily influenced by by-product utilization but scores among the best when compared to commercial seafood species and terrestrial animals per *kg* edible, per 100 *grams* protein, and per 1000 *kcal*. In summary, the orange-footed sea cucumber scores the best according to the NDS without capping for the species analysed, the pearlside scores best in energy-providing nutrients, while the herring scores the best for GHG emissions and according to NDS with capping.

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Appendix 1

Tabell 1. Summary of catch loggs from research fishery with pelagic trawl in 2019 (Øystein Lie, Senior Advisor at Liegruppen AS, E-mail November 2020). All values are given in kg.

Haul #	**Pollock**	**Krill**	**Mackerel**	**Pearlside**	**Blue Whiting**	**Argentine**	**Herring**	**Common ling**	**Horse Mackerel**
	P. virens	*M. norvegica*	*S. Scombrus*	*M. muelleri*	*M. poutassou*	*A. sphyraena*	*C. harengus*	*M. molva*	*T. trachurus*
1	100	2 000	75	40 000					
2	800	500	160	35 000	7 000	300			
3		14 000		5000					
4	240	1000		6500	14 500	3 000			
5	100		60	15 000	1 000				
6	90	18 000		23 000					
7	240	3 000		27 000					
8	384	3 000		20 000	1 100				
9	100	1 000		39 000	500				
10	180	2 500	30	35 000					
11	100	150		5 000					
12	70	300		17 000	500				
13	312	11 250	10	13 750					
14	70	4 800	5	15 200					
15	10	100		900					
16	100	3 000		4 000	6 000	400			
17	320	900		14 000			350		
18	500	4 000		24 000	2 000				
19	428	3 000		21 000				3	
20	1 000			15 000	1 500				
21	652	2 000		25 000	500				100
22	600	9 000		27 000	2 000				
23	420	7 000		17 000	6 000				
24	300	10 000		24 000	10 000				
25	1 000	12 000		20 000	9 000				
26		7 360	40	11 600					15
27	30	6 000	4	4 000					
28		2 880	60	2 460	600				
SUM	**8 146**	**128 740**	**444**	**506 410**	**62 200**	**3 700**	**350**	**3**	**115**

Appendix 2

Tabell 2.Daily recommended intake and maximum recommended intake of macro- and micronutrients for men and women between 31-60 years. Table is adapted from calculations done by Hallström et al. (2019)

Nutrients	**Women** **31-60 years**	**Men** **31-60 years**
QUALITATIVE NUTRIENTS	**Daily recommended intake (DRI)**	
Protein (g/d) [1]	73.3	85.6
Fibre (g/d)	25-35	25-35
Omega-3 fatty acids (g/d)[2]	2.3	2.9
Retinol eq. (µg)	700	900
Vitamin D (µg)	10	10
Vitamin E (mg)	8.0	10
Thiamin (mg)	1.1	1.3
Riboflavin (mg)	1.2	1.5
Ascorbic acid (mg)	75	75
Niacin equivalents (mg)	14	18
Vitamin B6 (mg)	1.2	1.5
Vitamin B12 (µg)	2.0	2.0
Folate (µg)	400 [3]	300
Phosphorus (mg)	600	600
Iodine (µg)	150	150
Iron (mg)	15	9.0
Calcium (mg)	800	800
Potassium (g)	3.1	3.5
Copper (mg)	0.9	0.9
Magnesium (mg)	280	350
Selenium (µg)	50	60
Zinc (mg)	7.0	9.0
DIS-QUALITATIVE NUTRIENTS	**Maximum Recommended Intake (MRI)**	
Saturated fatty acids (g/d)[4]	23	29
Sodium (g/d)	2.4	2.4

[1] Its recommended 0.8 - 1.5 grams protein per kg body weight for adult. The average weight in Denmark, Finland, Iceland and Sweden is 74.4 for men age 31-60, and 63.7 for women in the same age group. The mean protein amount is used for calculation. [2] Intake of n-3 fatty acids should provide at least 1 E%. Energy estimates are at 11 MJ/d for men-, and 8.8 for women within the age group 31 – 60 year (Norden, 2014). E% is calculated according to (National Council for Nutrients, 2017). [3] Women of reproductive age are recommended to have an intake of 400 µg/d while 300 if not of reproductive age. [4] Intake of saturated fatty acids should be limited to 10 E% (Norden, 2014).