BIM Ireland's Seafood Development Agency

Carbon Footprint report of the Irish Seafood Sector

Bord Iascaigh Mhara

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Acronyms used

ASC	Aquaculture Stewardship Council
B2B	Business to Business
B2C	Business to Consumer
BIM	Bord Iascaigh Mhara
BRU	Biotic Resource Use
CFP	Common Fisheries Policy
CO_2 eq	Carbon Dioxide Equivalent
CSO	Combined Sewerage Overflow
DAFM	Department of Agriculture Food and the Marine
DCF	Data Collection Framework
DECC	Department of Environment, Climate and Communications
DPF	Diesel Particulate Filter
EC	European Commission
EF	Emission Factor
EGR	Exhaust Gas Recirculation
EMFAF	European Maritime Fisheries and Aquaculture Fund
EMFF	European Maritime Fisheries Fund
EPA	Environmental Protection Agency
ESI	European Structural and Investment (funds)
EU	European Union
FAO	Food and Agriculture Organisation
FEAP	Fishing Effort Adjustment Plan
FIBC	Flexible Intermediate Bulk Container
FTS	Flow Through System
FUI	Fuel Use Intensity
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GT	Gross Tonnage
GWP	Global Warming Potential
HVO	Hydrotreated Vegetable Oil
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IMTA	Integrated Multitrophic Aquaculture
kW	kilowatt
LCA	Life Cycle Assessment
LED	Light Emitting Diode
LNG	Liquid Natural Gas
LPG	Liquid Petroleum Gas
MSC	Marine Stewardship Council
OP	Operational Programme
PAS	Publicly Available Specification
PP	Polypropylene
PV	Photovoltaic
QMAC	Quota Management Advisory Committee
RAS	Recirculating Aquaculture System
RSW	Refrigerated Seawater
SCR	Selective Catalytic Convertor
SEAI	Sustainable Energy Authority of Ireland
SWAS	Solid Walled Aquaculture System
t	Metric Tonne
TOR	Terms of Reference
VCU	Vessel Capacity Unit
VSD	Variable Speed Drive
WTT	Well to Tank
WWTW	Wastewater Treatment Works

Contents

Executive Summary and Irish Seafood Sector Overview

The climate crisis is changing the world in which we live and is impacting on all aspects of life on our planet. A worldwide effort is underway to tackle this crisis and to ensure that sustainability is at the centre of every human activity.

All sectors of society are increasingly seeking to adhere to the sustainability principles as laid down by the United Nations Sustainable Development Goals (SDGs) and, as part of these efforts, are striving to achieve Net Zero carbon emissions by 2050 as agreed by 194 countries under the 2015 United Nations Paris agreement. It is now recognised that achieving sustainability and implementing climate action are essential steps to ensuring that the planet will be able to support a growing population of more than 8 billion people.

The fight against climate change is more evident than ever, and food production is seen as a key component in this struggle. Aquaculture and sea fishing, like all human activities, contribute to and will be highly impacted by climate change. A key challenge for current and future generations is to produce healthy and nutritious food in a way that does not harm the planet. In essence, there is recognition that human health is tightly connected to the health of ecosystems and the environment and that these ecosystems and the environment must be managed sustainably to protect ourselves.

To respond to these challenges and to limit the rise of average global temperatures to less than 1.5°C, all sectors of society are seeking to reduce greenhouse gas emissions. The Irish seafood sector is deeply conscious of sustainability and the decarbonising agenda and sees climate action and achieving Net Zero as a primary objective in the decades to come. The challenge for our sector is to continuously improve the way in which we grow and catch seafood. The opportunity is to provide the consumer with seafood that is healthy and nutritious and in so doing, to sustain a prosperous seafood sector that will continue to directly employ over 8,000 people in the coastal regions of Ireland.

This report provides a carbon baseline for the Irish seafood sector and is an excellent starting point on the journey to achieving Net Zero by 2050. Decarbonising will be an enormous task, but the benefits will be enormous too.

Section 1:
Carbon Footprint Report

Key points

- Overall, the Irish seafood sector is a relatively low carbon emitting sector i.e., the sector has a low carbon footprint. This is because of the small size of the sector relative to farming, energy production, transport and other sectors of the economy, and also the fact that Irish seafood has a low carbon emission profile per tonne of landings.
- Total carbon emissions for the Irish seafood sector are 396,207 tonnes CO_2 eq. This total figure covers both catch fisheries and aquaculture segments. This represents 1.76% of emissions when compared to Irish agriculture emissions (2017-2019 average).
- This study confirms that Irish seafood can generally be considered a 'low carbon food'.
- The Irish seafood sector is diverse, and the carbon footprint of different seafood products varies depending on the species in question and the methods used to cultivate or catch these species.
- The drivers for decarbonising the Irish seafood sector will intensify in the future. The main drivers for emission reduction are (i) national obligations to achieve Net Zero emissions by 2050, (ii) maintaining ecosystem biodiversity and sustainability, (iii) consumer demand for low-carbon products, and (iv) increasing fuel costs.

About this report

This report aims to develop a greenhouse gas emissions baseline for the Irish seafood sector, incorporating the Irish fishing vessel fleet and aquaculture, based on available data and a representative sample where available. The period 2017-2019 was selected based on available data at project commencement. The uncharacteristic 2020 period was ignored due to the impacts of the COVID-19 pandemic.

The following calculated carbon emissions data illustrates the emission or 'carbon footprint' of the Irish seafood sector, focusing on 'cradle to gate' boundaries of the Irish seafood life cycle. The emissions associated with Irish fishing vessels and aquaculture are detailed further in the following sections of the report. The figures presented in Table 1 are the estimated total emissions for the fisheries and aquaculture sectors. Table 1 also sets the absolute emissions values in the context of Irish agricultural emissions reported in the EPA's report, *Ireland's Provisional Greenhouse Gas Emissions 1990-2021*. Ireland's latest Greenhouse Gas (GHG) emissions (1990-2021) are provisional figures based on the Sustainable Energy Authority of Ireland's (SEAI) interim energy balance provided in June 2022.

These data are further broken down by Irish fishing vessel emissions (catch fisheries) and aquaculture later in the report. From these data it can be seen that GHG emissions reduce in absolute terms by 3% from 2017-2018 and by 13% from 2018-2019. There are many variables within the Irish seafood and aquaculture sector which will influence emissions. However, the significant drop from 2017 to 2019 is considered to be mostly as a result of the reduced seafood landings in 2019 and a significant reduction in farmed salmon production in 2018 and 2019 compared to 2017.

Table 1: Combined Irish Fishing Vessels and Aquaculture Absolute Greenhouse Gas Emissions.

Seafood Sector Emissions (Catch fisheries and Aquaculture)	Absolute Emissions 2017	Absolute Emissions 2018	Absolute Emissions 2019	Three-Year Average (2017-2019)
Absolute Scope 1 and WTT Scope 3 emissions (tonnes CO_2 eq.) for seafood sector	452,055.82	408,932.43	327,632.34	396,206.86
Agriculture EPA Emissions 2017-2019 (Provisional) (tonnes CO_2 eq.)	22,195,546.72	23,053,372.47	22,134,309.00	22,461,076.06
Irish seafood emissions data as a % compared with Agriculture (EPA emissions data 2017-2019)	2.04%	1.77%	1.48%	1.76%

Climate Change and the Seafood Sector

Analysis of meteorological data for Ireland shows that the climate has changed over the past 100 years. These changes are similar to regional and global patterns reported in the Intergovernmental Panel on Climate Change *Assessment Report 4* (IPCC, 2022).

The clearest trend is evident in the temperature records but there is also a trend towards more intense and frequent rainfall. River flows are generally increasing. Although, when more recent data for a shorter period have been analysed, there are indications that flows may be decreasing in the south and east of the country. Some of the indicators of climate change in Ireland are documented below:

- Satellite observations indicate that the sea level around Ireland has risen by approximately 2-3 mm per year since the early 1990s.
- The average sea surface temperature measured at Malin Head was 0.47°C higher over the last 10 years compared with the period 1981-2010.
- Measurements in the surface waters to the west of Ireland between 1991 and 2013 indicate an increase in ocean acidity that is comparable to the rate of change in other global ocean time series.
- Observations of some potentially harmful phytoplankton species since 1990 show an expansion of their growth season, with their presence being observed in almost all winter months since 2010.

These changes are reflected in ecosystem alterations, with increases in the growing season, and greater numbers of warm water aquatic species being evident in Ireland and its surrounding waters (Cámaro García and Dwyer, 2021). However, climate change impacts are projected to increase in the coming decades and during the rest of this century. Uncertainties remain in relation to the magnitude and extent of these impacts, particularly during the second half of the century. The greatest uncertainty lies in how effective global actions will be in reducing GHG emissions.

Predicted negative changes for Ireland (from the Environmental Protection Agency Climate Change Research Programme, especially Flood *et al.*, 2020 and the Agriculture, Forestry and Seafood Climate Change Sectoral Adaptation Plan) include:

- Increase in the pace of sea-level rise.
- More intense storms and rainfall events.
- Increased likelihood and magnitude of river and coastal flooding; increased storm surges.
- Changes in sea temperatures exceeding the tolerance limits of species.
- Changes in freshwater temperatures, dissolved oxygen and river flows with possible negative consequences for fish growth and survival and knock-on impacts in estuaries.
- Increases in ocean acidity in Irish waters (with implications for shell-forming organisms).
- Further changes in the distribution and abundance of harmful algal species in Irish waters with implications for finfish and shellfish aquaculture.

- Changes in the distribution and abundance of pathogenic bacteria within Irish waters with implications for finfish and shellfish aquaculture.
- Potential lack of access to freshwater and other resources.

The Department of Agriculture Fisheries and the Marine's (DAFM) *Agriculture, Forestry and Seafood Climate Change Sectoral Adaptation Plan* was published in 2019 (DAFM, 2019). This establishes the projected changes in climate, focussing on those identified as most likely to impact the agriculture, forestry, and seafood sectors.

In October 2020 the Department of the Environment, Climate and Communications (DECC) committed Ireland to move to a climate-resilient and climate neutral economy by 2050, through Ireland's Climate Action and Low Carbon Development (Amendment) Bill 2020. This commits to a 7% average yearly reduction in overall greenhouse gas emissions over the next decade and achieving Net-Zero carbon emissions by 2050. In November 2021 the DECC published the *Irish National Climate Action Plan 2021* which sets out how the country will achieve the average 7% annual reduction in emissions.

Section 2:
Irish Fishing Fleet Emissions Review

Key points

- The Irish fishing fleet is a relatively low GHG emission sector. The fishing sector contributes 83.5 % of total seafood GHG emissions and is 1.47% when compared to Irish agriculture emissions (2017-2019 average).
- The pelagic fishing fleet has a particularly low carbon footprint. The GHG emissions for RSW caught Atlantic mackerel are 0.23 tCO_2 eq./t landings.
- In fishing, over 90% of GHG emissions are related to the combustion of diesel aboard vessels.
- The carbon footprint of seabed trawler fisheries is higher than that of pelagic fisheries (on a per tonne of landing basis). Seabed trawling increases load on engines and therefore increases GHG emissions.
- Innovations in areas such as net design and fish finding technologies will serve to reduce carbon footprints through more targeted and selective fishing effort.

An absolute GHG value was calculated for all Irish fishing vessels registered for 2017, 2018 and 2019. This absolute GHG value (330,888 tCO_2 eq) was calculated by scaling up the emissions data obtained from a sample of the fishing fleet. For each year 2017-2019 inclusive (Table 2), emissions are presented as combustion only (Scope 1 emissions of the vessel associated with combustion of the marine diesel) and also combustion and Well-To-Tank (WTT) emissions (well-to-tank includes all GHG emissions from the production, transportation, transformation and distribution of the fuel used to power the vessel, i.e., Scope 3 emissions).

There was a 4.2% increase in emissions from 2017 to 2018. However, following this there was a 22.5% emissions reduction from 2018 to 2019. Overall, there is an absolute emission reduction of 25.8% from 2017 to 2019. A breakdown of emissions is provided below, further detailing the emissions profile of the Irish seafood sector. As the emission calculations are based on sample data from the industry this may have affected the results.

Table 2: Irish fishing fleet (active) absolute greenhouse gas emissions (tCO_2 eq) 2017-2019.

Irish Fishing Vessels Emissions*	Absolute Emissions 2017	Absolute Emissions 2018	Absolute Emissions 2019	Three-Year Average (2017-2019)
Scope 1 (combustion only) (tCO_2 eq.)	298,883	286,764	222,158	269,269
Scope 1 + WTT Scope 3 emissions (tCO_2 eq.)	367,740	352,134	272,788	330,888

* Fuel only covering >97% of Vessel GWP Impact and incorporating vessel 'activity factor'.

Irish Fishing Fleet Overview

This report sees the development of a GHG baseline for the Irish fishing fleet based on available data and a representative sampling approach of the Irish fishing fleet. Data on the Irish fishing fleet split by vessel segment was sourced within Bord Iascaigh Mhara (BIM) and covers the period 2017-2019. A review of the Irish fishing fleet was conducted to provide a representative average of vessel landings and associated emissions and are in line with the project's Life Cycle Assessment (LCA) component. The LCA analysis covered a three-year period to provide a representative average as per PAS 2050-2 requirements.

The European Commission's EU MAP establishes a European Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy (CFP). BIM collated and provided the Irish fishing vessel data relevant to this project's scope. Data for 2020 was excluded by the study. It was considered that 2020 data may not be complete for use at the outset of the project and is likely to be atypical given Covid-19 impacts on operations and markets. For the purpose of this study the Irish fishing fleet was aggregated into the segments shown in Table 3.

Table 3: Number of registered Irish fishing vessels (active and inactive) by segment between 2017-2019.

Vessel Segment Type	2017	2018	2019	Average
Beamer	14	15	14	14
Freezer	59	62	57	59
Hake Gillnetters	9	11	11	10
Potter 0-12m	800	840	867	836
Prawns and Whitefish 12-18m	41	45	41	42
Prawns and Whitefish 18-24m	33	35	30	33
Prawns and Whitefish 24-40m	24	25	27	25
Seiners	9	9	9	9
Refrigerated seawater vessels (RSW)	23	23	23	23
Other*	942	985	868	931
Aquaculture**	97	100	91	96
Total	**2,051**	**2,150**	**2,038**	**2,080**
Total excluding aquaculture	**1,954**	**2,050**	**1,947**	**1,984**
Vessels number sampled	**226**	**140**	**169**	**178**
Sample %	**12%**	**7%**	**9%**	**9%**

* The 'Other' segment is made up of 26 small distinct segments.
** Aquaculture vessels were excluded from the totals and are considered in the aquaculture report section.
The methodology used is outlined in the supplementary information accompanying this report.

Section 3:
Irish Fishing Fleet Fuel Use Analysis

Key points

- Irish fishing vessel sample data analysed between 2017-2019 - which included both energy costs and tonnes of fish landed - gives an average emissions figure of 1.03 tCO_2 eq./t fish landed. This figure is well below the global seafood average of 1.7 tCO_2 eq./t fish landed.
- The calculated average of 1.03 tCO_2 eq./t fish landed is low compared to emissions associated with equivalent quantities of meat and dairy products.
- Fuel usage per tonne of landing is in the same range as other European fishery fleets.
- Patterns seen in international fleets are also seen in the Irish fleet. For example, the Irish refrigerated seawater (RSW) pelagic fleet is the most efficient in terms of carbon emissions per tonne of landings.

An absolute GHG emission value was calculated during this project for all Irish fishing vessels registered in for 2017, 2018 and 2019. This absolute GHG emissions value was calculated by scaling up the emissions data obtained within the fleet segment vessel sampled based on the total number of active vessels per segment category. In Table 2, for each year 2017-2019 inclusive, emissions are presented. As combustion only (scope 1 emissions of the vessel associated with combustion of the marine diesel) and also WTT emissions (Scope 3, well-to-tank includes all GHG emissions from the production, transportation, transformation, and distribution of the fuel used to power the vessel).

Normalised Irish Fishing Vessel Greenhouse Gas Emissions by total fleet sampled

Irish fishing vessel sample data analysed between 2017-2019 which included both energy costs and tonnes of fish landed provided an average of 1.03 tCO_2 eq./tonne fish landed. Each sample reference point included both an energy cost (subsequently converted into an emissions value) and a tonnes fish landed value for a particular vessel. Some vessels provided reference points across more than one year. Sample reference points covered only 2017-2019 inclusive. The sample reference points totalled 218,148 tonnes fish landed and 224,218 tCO_2 eq. emissions associated with marine diesel use (combustion emissions only). Extending the calculation to include the sum of tonnes CO_2 eq. WTT Scope 3 emissions, gives an average of 1.26 tCO_2 eq./tonne fish landed.

Average tCO_2 eq./tonne of fish landed per fleet segment

Table 4 and Figure 1 illustrate the emissions by vessel segment using the methodology and sampling approach outlined in Section 1.

Table 4: Average tonnes CO_2 eq. emitted by an average vessel per tonne of fish landed, presented by vessel segment.

Vessel Segment	Average tCO_2 eq. Scope 1 per vessel	Average Tonnes Landed per vessel	Emissions per tonnes of fish landed (tCO_2 eq./t) (2017-2019)
Freezer Trawlers	1,282.07	247.87	5.17
Beamer	930.34	221.68	4.20
Hake Gillnetters	483.74	152.76	3.17
*Other	429.01	181.91	3.07
Prawns and Whitefish 12-18m Trawlers	312.84	106.43	2.94
Prawns and Whitefish 18-24m Trawlers	966.67	469.43	2.06
Seiners	521.67	332.22	1.57
Prawns and Whitefish 24-40m Trawlers	1516.87	988.17	1.54
Potter 0-12m	46.62	35.03	1.33
RSW Pelagic	1421.14	6058.67	0.23

* Average tCO_2 calculated by segment and summed up to a general 'Other' category.

Table 4 above shows that the RSW pelagic fleet is the most efficient in terms of carbon emissions per tonne of landings. Freezer trawlers are not as efficient in carbon emission terms. Figure 1 is a graphical representation of the Table 4 data and shows the different Carbon emission profiles in the Irish fleet segments. It should be noted that these patterns are seen in international fleets and that these emissions are at the lower end when compared to farming.

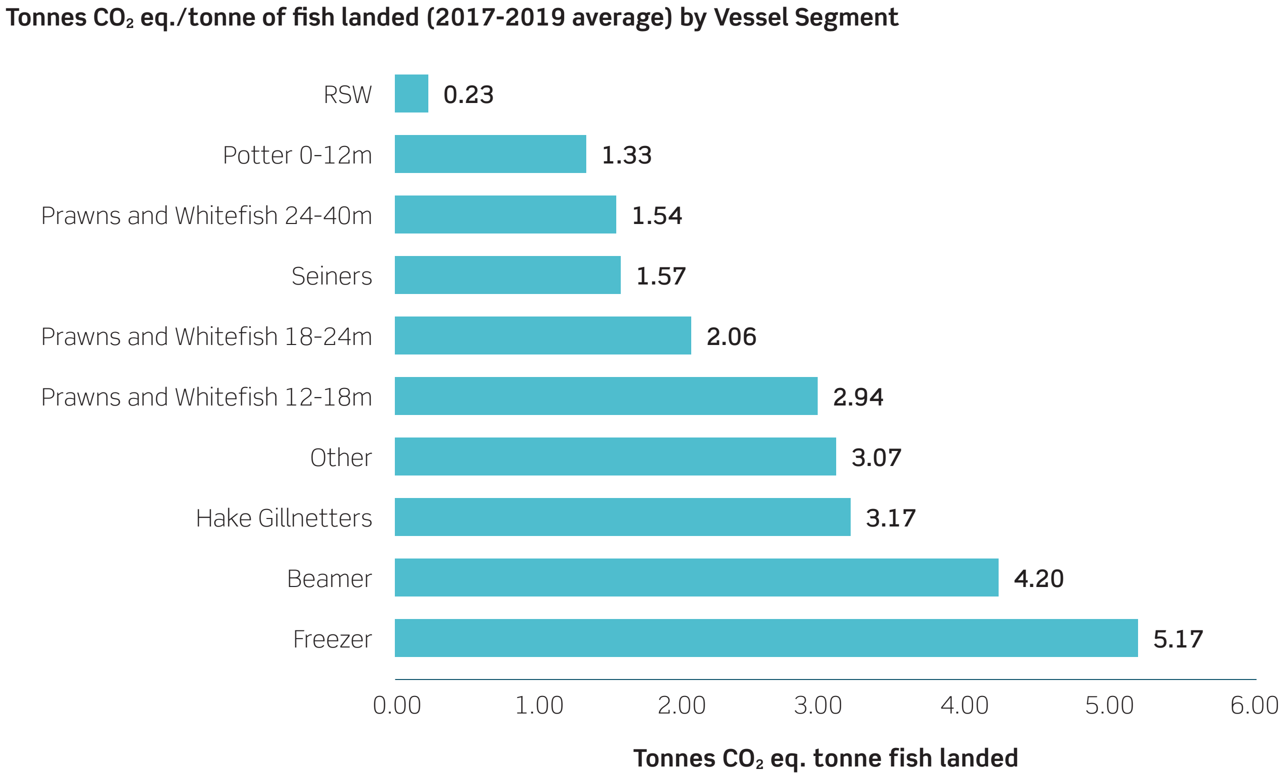


Figure 1: Average tonnes CO_2 eq. emitted by a vessel per tonne of fish landed, by vessel segment.

A recent study on global GHG emissions and fuel use by fishing, estimated that, to land 1 kg of fish (or invertebrates), 2.2 kg CO_2 eq. were emitted (Parker *et al.*, 2018). Within that study they also demonstrated regional differences in fuel use and emissions. Latin America had the lowest use of fuel (235 L/t) and emissions (1 kg CO_2 eq./kg), while China had the highest (809 L/t and 3.7 kg CO_2 eq./kg). These relatively large differences in fuel and emissions were driven by numerous factors associated with the species being targeted. For example, in Latin America the primary species caught was the *Peruvian anchoveta*, which due to its abundance and shoaling nature, requires a low input of fuel to catch. The higher fuel usage and emissions for China, were due to their targeting of crustaceans, as these have a lower stock density and require greater effort to catch. The Parker study also estimated the average global emissions for different fishing segments, with pelagic fish (<30 cm) being the most efficient at 0.2 kg CO_2 eq./kg, pelagic fish (>30 cm) at 1.9 kg CO_2 eq./kg, and crustaceans at the higher end at 7.9 kg CO_2 eq./kg.

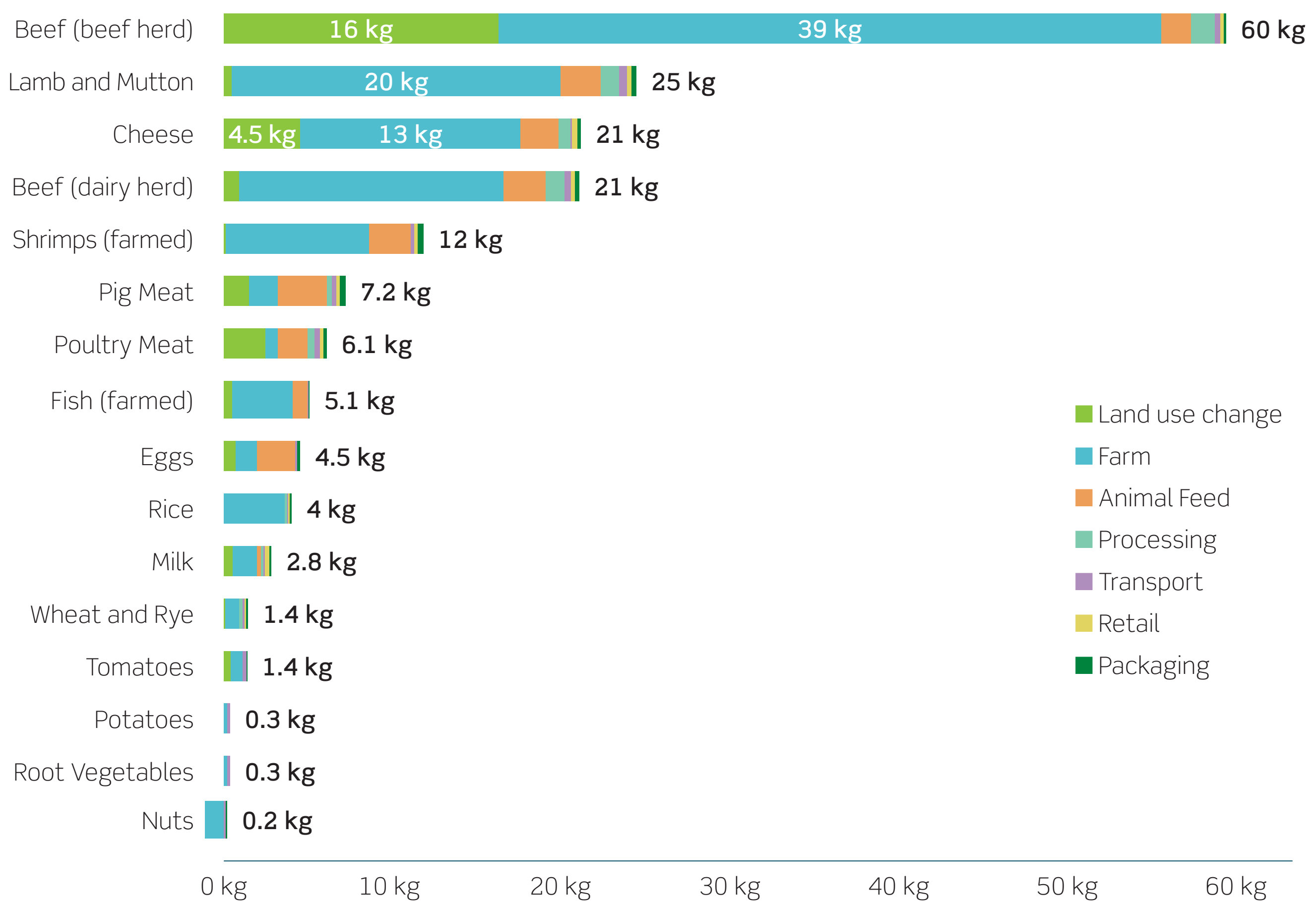
It is important to contextualise these figures with global catch as, while crustaceans had higher emissions, they contributed less than 6% of total catch and the pelagic categories accounted for 47% of global catch. The Irish fleet performs well in the context of global fleet emissions. It is at the lower end of the emission profiles, as reported by Parker *et al.*, (2018).

- The calculated average of 1.03 tCO_2 eq./tonne of Irish landed is low when compared to other animal proteins (Figure 2). Beef and lamb are known to have significant carbon emissions. Wild caught seafood, on the other hand, has emissions that are only a fraction of farmed livestock. This is primarily because farm animals emit methane as part of their digestive process (i.e., enteric fermentation).

- This study focuses on the carbon footprint of a tonne of landed fish (tCO_2 eq./tonne). Landed fish at port, obviously include bones and viscera that are subsequently removed via processing. Therefore, a fillet of fish would seem more comparable to a steak for example: One approach to solving this 'compare' problem is to use conversion factors. However, conversion factors vary depending on the fish species in question, but an average conversion factor of 2.7 for live weight of fish is common. However, even when these conversions are applied, the carbon emissions from fish products remain significantly lower than those of land-based animal protein. Figure 2 shows a comparison of carbon emissions across different food types. Meat, dairy and lamb display relatively high emissions in this context, while wild caught seafood is at the lower end of the range.

Food: Greenhouse gas emissions across the supply chain

Emissions are measured in carbon dioxide equivalents (CO_2 eq). This means non-CO_2 gases are weighted by the amount of warming they cause over a 100-year timescale.



Source: Poore, J., and Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science.

Note: Greenhouse gases are weighted by their global warming potential value (GWP100). GWP100 measures the relative warming impact of one module of a greenhouse gas, relative to carbon dioxide, over 100 years.

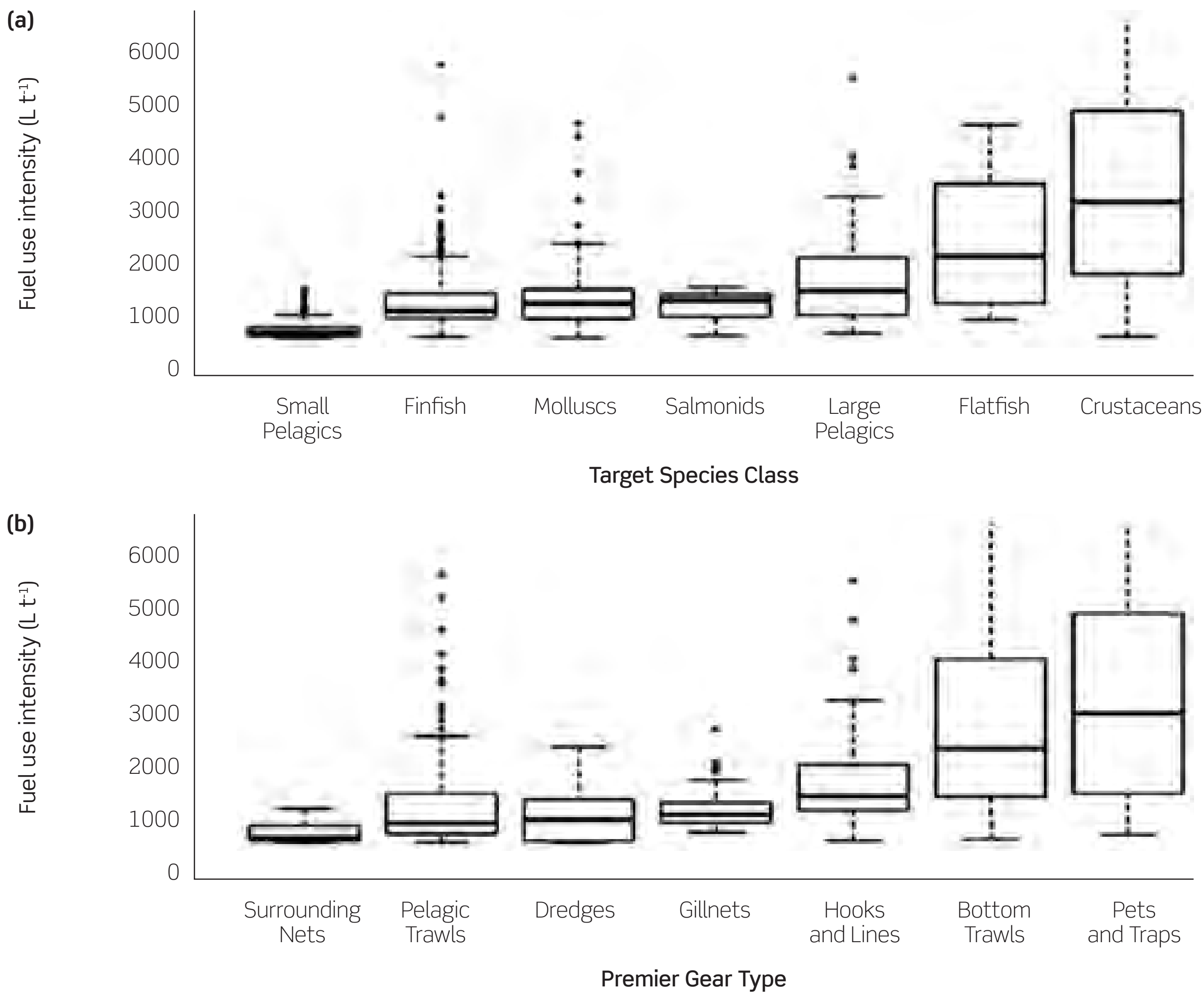
Figure 2: Greenhouse gas emissions of different foods (Adapted from Poore and Nemecek, 2018).

Irish fish landing emissions and comparing to other fishing fleets

Tydemers *et al.*, (2006) estimated a global seafood average of 1.7 tCO_2 eq./t, so 1.03 tCO_2 eq./t for Ireland is below the global average. This is expected given the large proportion of Irish catch coming from Ireland's pelagic fisheries and the low carbon emitting (per tonne of landing) RSW segment. Greer *et al.*, (2019) report emission intensity per tonne of catch in European fisheries to average 1.1 tCO_2 eq./t. The slight difference between Irish and European values, could be the result of different catch profiles, including the dominance of pelagic catches.

The results for the 'seiner' segment are similar to those of the RSW fleet segment.

Parker and Tydemers (2014) shows the variation between fleets with different target species and gears (Figure 3 below). In terms of days fished, Irish fishing effort is dominated by demersal prawn and whitefish fisheries, and there are significant dredge fisheries for scallops. A higher fuel intensity for the Irish fleet would result if metrics such as CO_2 equivalent per fishing per day or per kW hour were applied.



* boxes represent 25th and 75th percentiles. Dots denote outliers. Graph is truncated at 6,000l but some values for crustacean fisheries are higher.

Figure 3: Median and range of fuel use intensity (FUI) records by (a) species and (b) gear type (source: Parker and Tydemers, 2014).*

Freezer Fleet

The average emissions per tonne landed for this segment was calculated to be 5.17 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum sample value was calculated as 2.4 tCO_2 eq./t, and the maximum 10.75 tCO_2 eq./t.

The Freezer trawler fleet comprises around 60 vessels, made up of vessels mostly in the size range 22-27 m with an average tonnage of 214 GT and engine power of 500 kW. They fish around 250 days per year and the vessels have an average age of 26 years with several new vessels entering the fleet in the last 5 years. This fleet exhibits the highest fuel use/emissions per tonne of seafood landed in Ireland. These higher emissions can partially be explained by the additional energy/fuel expended in the primary processing (i.e., cleaning, grading, boxing, freezing) of the catch. No other fishing segment processes to this level at sea.

These vessels use bottom towed gear and target *Nephrops*, which show relatively high Fuel Use Intensity (FUI) compared to other targeted species groups. The difference between the Irish freezer segment and the prawn/whitefish segments is striking given that they operate similar gears (demersal stern trawlers – mostly twin-rig with two nets or quad-rigged with four nets). Their high FUI may be due to the more targeted nature of the fishery and the ability to operate longer trips (freezing prawns at sea over longer fishing trips (typically 8-10 days) rather than a more mixed catch by prawn/whitefish vessels. It may also be due to the fishing locations; the frozen at sea market favours the larger sized prawns found at the Porcupine bank and so relatively more fuel may be spent steaming. Deep water fishing also takes a lot longer to haul gear and will require more fuel for this exercise.

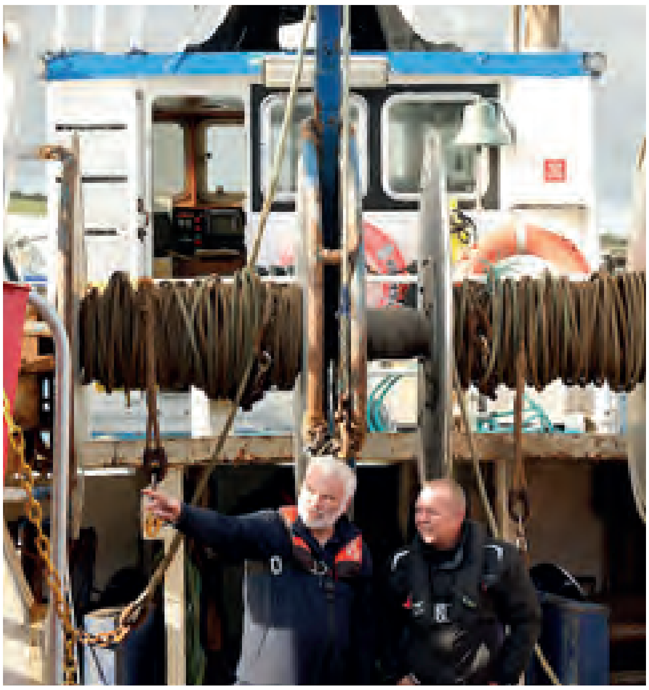
The contribution of freezer units to the overall vessel energy demands requires deeper investigation as refrigeration/fuel use data was not available for this study. Feedback from skippers suggest the blast freezers account for circa 5% to 10% of fuel used. This proportion is significant, if accurate, and investigating more efficient freezing options could make economic as well as environmental sense.

Beamer

The average emissions per tonne landed for this segment was calculated to be 4.20 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 1.40 tCO_2 eq./t, and the maximum 8 tCO_2 eq./t.

The Beam trawl fleet comprises around 14 vessels, made up of vessels mostly in the size range 24-28 m with an average tonnage of 111 GT and engine power of 271 kW. The engine power of most of these vessels is restricted to 221 kW under EU and national fleet policy. The beam trawl fleet fish, on average, around 220 days per year and the vessels have an average age of 32 years. No new vessels have entered this fleet segment in the last 10 years.

Beam trawlers use heavy bottom trawl gear comprising short nets stretched across a rigid beam that runs on sleds at each end. Heavy 'tickler chains' and chain mats are used to move fish out of the sediment. Traditionally, beam trawling is considered one of the most fuel-intensive fishing methods, but this segment has remained economically viable as the vessels target high value flatfish species such as sole, turbot and megrim as well as anglerfish and rays. Consequently, they are highly impacted by fuel price increases, and given their age and general design are not easily converted to other forms of more fuel-efficient fishing methods.



Hake Gillnetters

The average emissions per tonne landed for this segment was calculated to be 3.17 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 1.71 tCO_2 eq./t, and the maximum 12.43 tCO_2 eq./t.

The hake gillnet fleet comprises around 10 vessels, made up of vessels across a wide size range from 12-27 m and with an average tonnage of 53 GT and engine power of 184 kW. The hake gillnet fleet fish around 150 days per year, working 3–10-day trips. The vessels have an average age of 31 years. No new vessels have entered this fleet segment in the last 10 years although several modern second-hand smaller vessels have been brought in as replacement vessels.

Gillnets are classified as static gears, which intuitively should be less fuel intensive than towed gear such as that used by prawn and whitefish trawlers. It is therefore surprising to see it placed above some of the demersal trawl segments. However, the gillnet fleet is made up of a mixture of small purpose built 12-14 m vessels as well as several converted trawlers that are over-powered for gillnetting and so use more fuel in steaming than would normally be required by purpose-built vessels. This may also in part be data-driven (a relatively small sample size) and the targeted nature of the fishery (the catch volumes can be relatively low compared to other fishing methods). As identified in the Marine Institute's commercial fisheries atlas, gillnet effort by Irish vessels is distributed widely over the continental shelf with small areas of high effort in the south and southwest. (Marine Institute, 2019). Gillnetting also requires regular shooting and hauling of nets (typically hake gillnets are left to soak for 20-24 hours at a time), therefore fishing activity is around the clock with frequent steaming between deployed nets.

Prawns and Whitefish

For this analysis the prawn and whitefish trawl fleet has been split into three vessel size ranges - 12-18 m, 18-24 m and 24-40 m with the later also containing polyvalent pelagic (tier 1) vessels. Freezer trawler vessels that would sit within these size categories are covered above. These vessels target a mixture of demersal species and prawns, as well as pelagic species seasonally.

The average emissions per tonne landed for the Prawns and Whitefish 12-18 m segment was calculated to be 2.94 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 0.94 tCO_2 eq./t, and the maximum 6 tCO_2 eq./t. The 12-18 m fleet segment comprises around 40 vessels, with an average tonnage of 50 GT and engine power of 170 kW. These vessels fish around 120-150 days per year, working 1–3-day fishing trips. The vessels have an average age of 38 years. No new vessels have entered this fleet segment in the last 10-15 years apart from several like-for-like secondhand vessels with similar characteristics.

The average emissions per tonne landed for the Prawns and Whitefish 18-24 m segment was calculated to be 2.06 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 0.55 tCO_2 eq./t, and the maximum 8.06 tCO_2 eq./t.

The 18-24 m fleet segment comprises around 35 vessels, with an average tonnage of 144 GT and engine power of 400 kW. These vessels fish around 220 days per year, working 3–7-day fishing trips. The vessels have an average age of 29 years. Newer secondhand vessels have entered the fleet in the last 5 years on a regular basis and several new vessels have also been brought in.

The average emissions per tonne landed for the Prawns and Whitefish 24-40 m segment was calculated to be 1.54 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 0.31 tCO_2 eq./t, and the maximum 16.13 tCO_2 eq./t.

The 24-40m fleet segment comprises around 16 vessels, with an average tonnage of 265 GT and engine power of 620 kW. These vessels fish around 200 days per year, working 3–10-day fishing trips. The vessels have an average age of 25 years. Vessels in this segment are highly mobile and some switch between targeting whitefish and prawns to pelagic species such as Atlantic mackerel, horse mackerel and albacore tuna on a seasonal basis. As with the 18-24 m fleet segment, newer secondhand vessels have entered the fleet in the last 5 years on a regular basis and 8-10 new vessels have also been brought into the fleet in recent years.

The three size ranges show reduced emissions per tonne landed from the smallest to largest vessels. These results are logical as economies of scale are achieved by the larger vessels, but operational differences and the fisheries the vessels operate are also important factors. The larger vessels in these segments are quite dynamic and diversify between different fisheries. They also use a range of trawl configurations from single rigs to twin rigs to quad rigs in the case of prawn vessels as well as pelagic trawl gear as indicated above.

It is difficult to directly compare the prawn and whitefish results to those of other LCA studies of *Nephrops* fisheries. Ziegler and Valentinsson (2008) found that conventional trawling used 8.6 ± 4.2 litres of diesel per kilogram of Norway lobster landed (*Nephrops* representing 70% of the catch value as opposed to 59% as reported in the statistics). However, the allocation and functional units differed, with the results used to compared with an alternative fishing method (creel) rather than other LCA studies.

Seiners

The average emissions per tonne landed for this segment was calculated to be 1.57 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 1.13 tCO_2 eq./t, and the maximum 2.10 tCO_2 eq./t.

The seine net fleet comprises around 9 vessels, made up of vessels across the size range from 16-27m and with an average tonnage of 163 GT and engine power of 373 kW. The seiners fish around 200 days per year, working shorter trips compared to similar sized trawlers of 3-5 days to maximise fish quality. The vessels have an average age of 36 years. No new vessels have entered this fleet segment in the last 10-15 years apart from several like-for-like secondhand vessels with similar characteristics.

Seiners or fly-shooters use thick rope warps (seine ropes) to herd fish into the net, Seine nets tend to be of lighter construction compared to trawl gear and as they also do not use trawl doors to spread the net, they are more fuel-efficient than trawlers. They also only operate during daylight hours, tending to make up to 7 hauls (or rings) per day. They target shoaling species such as haddock, hake and whiting and avoid areas of rough ground. These factors explain the tCO_2 eq./t value for the Irish seiner fleet of 1.57 tCO_2 eq./t which is significantly lower than other bottom-contacting mobile gear.

Potters 0-12m

The potters 0-12 m fleet segment forms a large part of the overall inshore fisheries fleet. In total the inshore fleet on average is in the region of 830 vessels. It is split into around 720 vessels under 10m and 110 vessels between 10-12 m. The under 10 m vessels have an average tonnage of 2GTs and engine power of 20 kW, while the 10-12 m potters have an average tonnage of 11 GT and engine power of 77 kW. These vessels fish for less than 24 hours a time and as their operations are weather dependent and seasonal in nature, they tend to fish less than 100 days per year. Some larger vessels in the 10-12 m size range can fish up to 150 days. The average age of these vessels is 33 years and replacement vessels, both new and secondhand, are brought into the inshore fleet regularly.

The potters mostly target crab, lobster, shrimp and whelk, although some diversify into other fisheries such as the hook and line fishery for Atlantic mackerel or gillnet fishery for pollack, rays and turbot. As may be expected for this coastal static gear fishery, the 0-12 m potting fleet shows low emissions per tonne landed. The segment catches small volumes of high value species, contributing a small % of Ireland's total catch. It should also be noted that direct fuel use in these fisheries is likely to be a lower proportion of overall emissions than in other fisheries. The potters fleet segment use bait, which potentially can be a contributor to GHG emissions. Bait was not assessed as part of this analysis as it focused on vessel fuel use. The contribution of bait to overall emissions will depend on the source, for example, small pelagics such as Atlantic mackerel have far lower emissions than bycatch from trawl fisheries. Background processes and practices such as the storage of bait in freezers ashore should also be considered as part of an LCA. The contribution of bait to overall fleet emissions should therefore be considered for this fleet segment and is an area for future research.

In addition to the large fleet of potters, there are also a smaller number of potting vessels over 12 m. This includes 3 larger vivier crab vessels with much larger tonnage and engine powers. These vessels work further offshore and for part of the year operate in the North Sea, fishing longer trips of 5-8 days. As they keep the crab catch alive in specialised vivier tanks they have higher emissions than the smaller potting vessels. Their emissions profile is similar to the hake gillnetters.

Refrigerated Seawater Vessels (RSW)

The average emissions per tonne landed for this segment was calculated to be 0.23 tCO_2 eq./t of fish landed annual average (2017-2019). The minimum value was calculated as 0.13 tCO_2 eq./t, and the maximum 0.45 tCO_2 eq./t.

The RSW pelagic trawl fleet comprises 23 large, modern vessels, made up of vessels across the size range from 24-70 m and with an average tonnage of 1,080 GT and engine power of 2,048 kW. RSW vessels fish on average 60-70 days per year working short trips of sometimes less than 24 hours depending on the location of the target species. These short trips are needed to maximise fish quality. This fleet segment is the most modern in the Irish fleet with an average vessel age of 16 years. There has been frequent replacement of vessels with new efficient vessels.

RSW vessels show the lowest carbon emissions per tonne landed, despite their size and engine power. This is mainly because of the design of the vessels and the way they operate. They target high-volume pelagic fisheries using sophisticated fish-finding equipment and only fish for short periods of time. The fishing grounds tend to be close to harbour and steaming is kept to a minimum. Additionally, they use large mid-water nets with very large meshes in their fore part. They are designed to create as little drag as possible with minimal seabed contact.

The total reported for RSW fleet segments of 0.23 tCO_2 eq./t is close to a recent study of Shetland's pelagic fisheries. Sandison *et al.*, (2021) calculated the tCO_2 eq./t of fish for the mixed pelagic stock as 0.481 tCO_2 eq. The Irish fleet results are lower than studies of other European pelagic fisheries such as Winther *et al.*, (2019) (0.75 tCO_2 eq./t).

Section 4: Mitigation Measures

Key points

- Data and knowledge management are key areas of focus for the future so that the sector can keep informed as to the latest research, industry trends, and sectoral environmental and carbon performance.
- The fleet should implement decarbonising strategies and plans. The primary area for reducing the carbon footprint of capture fisheries relates to fuel use aboard vessels as this represents the largest single contribution to GHG emissions for this sector.
- Gear modification and innovative technology will continue to be a feature of carbon mitigation in the future. In general, lighter gear and a more targeted fishing effort using sonar and other ground discriminating technologies leads to lower fuel consumption.
- Alternative fuels such as hydrogen will feature in the future. In the short term, fuels such as biodiesel may form part of a 'transitioning' strategy i.e., lower emission fuels (bio diesel/HVO) that can be put into existing engines could be used while the fleet prepares to move to zero carbon fuels such as hydrogen or ammonia.
- In the medium term, hybrid engines will feature in terms of decarbonising the fishing fleet with 'pure' electric engines playing a role for the inshore fleet. Vessel retrofitting with more efficient engines and propellers will be important also.
- Carbon offsets by using nature-based solutions will be part of carbon mitigation plans in the future.
- Fisheries management needs to be increasingly adaptable, flexible, and responsive to change. Overarching fisheries management (especially quota management) needs to consider the operational requirements of the fleet to allow for carbon emission reduction.
- Food waste (and co product loss) is a major indirect source of emissions across the food supply chain. To achieve reductions in food waste, significant supply chain, market and consumer knowledge is required as well as a collaborative approach, with fishers, processors, retailers and the food service sectors working together to tackle emissions.

General Fleet Emission Reduction Measures

Knowledge Management

Environmental performance, carbon emissions and climate change are all active research areas. It is important that the Irish fishing sector stays informed on emerging topics, trends, innovations, and the latest research in relation to improving environmental performance and bringing confidence to buyers and consumers in relation to the environmental credentials of Irish seafood. Consideration should also be given to the establishment of relevant networks (i.e., research and development, academic) to enable knowledge transfer and stakeholder engagement between all actors in Ireland's seafood economy.

Data Management

Data management is key to understanding fuel consumption and emissions. By fitting a fuel meter to a vessel, skippers can use software to see how much fuel is being burned during distinct phases of fishing operations. High resolution datasets are required so that skippers can determine the fuel use upon steaming, fishing, and hauling. When fuel use and landings data are combined and analysed, insight in relation to optimal fishing tactics can be generated.

At a sectoral level, the development of a national fuel use dataset would enable the sector to track emissions and use this dataset to develop fuel saving measures and to model the impact of different strategies such as the use of hybrid engines across a fleet segment.

Consideration should be given to the creation of an industry-wide fuel audit scheme to highlight areas for improvement.

The scheme could focus solely on fuel efficiency, or it could take a wider energy audit approach with all systems reviewed including hydraulics and refrigeration, as Alaska's SeaGrant Vessel Energy Audits do. The data gathered would allow individual vessel and fleet performance to be assessed over time, resulting in reductions in both economic and environmental costs.

Management and Regulation

Governance and fisheries management is a major part of the CFP, and this forms a backdrop for vessel activities. More specifically, the quota allocation system has a considerable influence on a vessel's fishing pattern and therefore impacts on a vessel's fuel use. Many Irish vessels receive monthly allocations on a 'use it or lose it' basis as set by the Quota Management Advisory Committee (QMAC), so vessels don't have complete flexibility to fish as to when it is most optimal in terms of the market, or indeed the weather. One consequence of this is that individual operators in the whitefish sector who are given a monthly allocation, cannot optimize their fishing patterns to the extent of pelagic operators who are given an 11-month window in which to use quota. The quota available to vessels affects the length of trips and so the amount of steaming time between grounds. This variability in fishing effort means that it is difficult to optimise fuel use. The impact of quota allocations on fishing patterns is perhaps most evident in the *Nephrops* fishery where many vessels divide their fishing time between the Irish Sea, the Smalls, and the Porcupine Bank. Vessels in this fishery are provided monthly quotas. One skipper suggested that if there were 2-3-month quotas, this would allow for more efficient fishing.

Fuel Use Efficiency

Fuel is the major source of GHG emissions for the Irish fishing fleet. BIM's 2009 report *Improving Fuel Efficiency on Fishing Vessels*, discusses the key aspects to ensuring fuel efficiency aboard Irish fishing vessels. Central to this is having a solid understanding of fuel usage. To this end it is recommended that vessels fit a fuel meter, carry out regular maintenance, and be aware of optimal speed with respect to fuel consumption.

It is important to note that fuel efficiency is not all about the engine. The influence of the gear in mobile gear segments is significant. When a net is 5-6 years old the net becomes less efficient at catching fish. In addition, new net designs and trawl doors have improved to lessen drag. Nets are smaller, stronger, and designed to be more efficient with lighter, stronger material and improved water flow, resulting in it being easier to tow. Despite the high cost for a new net, fuel savings make for a strong business case. New trawl door designs with fins can be easier to tow than the original three door design. One skipper reporting an estimated 50% less drag, additionally, new designs can also help to spread the net better at lower speeds, resulting in further fuel savings. There are also innovative steerable doors to further reduce drag.

Gear Modifications

In the short term, gear technology has major potential to improve carbon and fuel efficiency, in particular for bottom trawls. For example, BIM have commenced work on developing a more hydrodynamic net and off-bottom doors for the *Nephrops* fishery. Preliminary results show an estimated 29% reduction in fuel intensity (litres per kg landed) in the new four-panel trawl with enlarged mesh in the top sheet (McHugh *et al.*, 2022). While some vessels are already using more hydrodynamic doors, major improvements in fuel efficiency are anticipated if the doors can be successfully elevated from the seabed.

BIM have previously conducted a study on a new catch sensor in the Irish *Nephrops* fishery. The trial aimed to incentivise avoidance of unwanted catches and improve catch and operational efficiency.

Developed initially for shrimp trawl fisheries in the Northwest Atlantic, the sensor was successfully calibrated to work with *Nephrops*. From the wheelhouse an underwater acoustics display tracked the *Nephrops* contacting a sorting grid with underwater cameras deployed in the trawl are used to verify catches (McHugh *et al.*, 2019). This technology improves the quality of landings and indirectly reduces fuel consumption.

Supports are needed to encourage uptake of more carbon efficient gears. The new EMFAF is focused on low carbon fishing activities and improved energy efficiency which will assist the industry addressing challenges around their carbon footprint.

Alternative Gears

In general terms, fishing with static gear (gill nets, longlines, pots) is less fuel intensive than mobile gear (trawls, dredge, fly shooting) which pulls gear through the water. This means that, in terms of emissions, steaming to and from the gear may become more significant than 'fishing'. Static gear requires checking and may also involve the use of bait, all of which contribute to emissions. Transitioning to static gear would involve significant changes to a vessel and to vessel tactics. A strategic shift from bottom trawl to static gear is not seen as a viable option in the context of most commercial fisheries.

Most emission reductions will be achieved through innovations around the way fishing is currently conducted. For example, some Irish *Nephrops* vessels are trialling a four-panel net instead of a two-panel net. The idea being that covering more ground for the same fuel consumed will lead to improved fuel efficiency. One skipper mentioned new sensor technology from Canada, which signals the boat when *Nephrops* are encountered. This live reading has the potential to improve fuel efficiency by reducing towing time as the sensor data shows whether an area has *Nephrops* or not. In general, more targeted fishing effort with sensors, sonar and other ground discriminating technologies leads to lower fuel consumption.

As with *Nephrops*, scallops are targeted with bottom-contacting mobile gear, mainly using dredges. These gears penetrate the seabed and are fuel intensive. To date, no commercially viable alternative gear for harvesting scallops has been available. 'Hand-dived' scallops are only an option in a small number of locations.

Transitioning from mobile to fixed gear is unlikely to be viable for the time being and the benefits in terms of carbon reduction remain unclear, in the context of the Irish fishing sector. Lastly, retro fitting older vessels with new engines, larger diameter propellors, stabilisers (e.g., Paravanes, gyrostabilisers) and other options offer possible alternatives to fishers to reduce their fuel consumption and CO_2 eq. emissions. However, these options are likely to be vessel specific and are outside the scope of this report.

Post-harvest Emissions

Similar to other Irish food products, most Irish seafood is exported. Therefore, there are significant opportunities across the food production sector to achieve emission reductions in terms of choosing low emission modes of transport. Similarly, food waste is a resource waste as well as an emission hotspot. Approximately 30% of all food is not eaten meaning this is clearly an area for emission reductions. To achieve reductions in food waste, significant market and consumer knowledge is required, and so too is a collaborative approach, with fishers, processors, retailers and the food service sectors working together to solve this major problem.

Alternative Fuels

A brief overview of the main technologies and their applicability to the Irish fishing industry is provided below. As a general note, infrastructure will need to be put in place before many or any of the following technologies can be widely adopted by industry.

Shore to Ship Power

Connecting to shore power (also known as cold-ironing) while at the quay side allows vessels to use electrical power for its systems, rather than using main and auxiliary engines. This approach is in use in Killybegs, Donegal. The Killybegs "Cold-Ironing Project" is estimated to save 96,000 litres of fuel and reduces GHG emissions by 2,000 tonnes of CO_2 eq./annum. The shore to ship power supply is also one of the measures required under the 2014 Alternative Fuels Infrastructure Directive (2014/94/EU).

Full Electric

Relying on battery packs, trip range is a limiting factor aboard fishing vessels. Full electric engines are currently only suited to inshore vessels. These engines are currently very expensive but will more than likely feature in the inshore fleet as prices decrease and range increases over time.

Hybrid Electric

Hybrid diesel/electric power offers significant potential for the Irish fishing fleet. The world's first hybrid fishing vessel (Karoline) came into pilot service in Norway in 2015. The vessel is equipped with two battery packs with 195 kWh capacity. It also has a powerful diesel engine which is used for steaming. The vessel switches to 'electric' for fishing, loading and unloading. The vessel runs on battery power for approximately three hours a day and is charged at port nightly.

Danish shipyard Karstensens Skibsværft is currently building a 65.9-metre pelagic trawler equipped with a hybrid propulsion system made up of a 2,920 kW diesel engine and battery pack. Other equipment such as winches and fish pumps will be fully electric. In an Irish context, BIM have demonstrated the emission reduction potential of hybrid electric systems through their research aboard the national diver training vessel in Castletownbere. The project resulted in the reduction of 5,800 kg CO_2 eq. and fuel savings in the region of 86%.

Hybrid power reduces emissions in a number of ways. Firstly, while using the battery pack, vessel emissions are greatly reduced and these are then recharged, ideally using clean energy. Secondly, the hybrid system ensures that the diesel engines are run in an optimal fashion thereby reducing emissions further. This hybrid engine optimality is of major significance for fishing vessels as engine load is highly variable across fishing operations. Generally speaking, it is felt that hybrid engines will play a major role in decarbonising the Irish fishing fleet.

Liquified Natural Gas

Liquified Natural Gas (LNG) is a fossil fuel, but it burns with fewer GHG emissions than diesel. LNG also has zero sulphur emissions which is beginning to be highly regulated in terms of emission levels in the transport fleet. In Scandinavian countries, current indications suggest that LNG will play a key role in the medium to long term future of these fishing fleets.

Biofuels

Biofuels can be added directly to existing engines with minimal modifications. The key point is that these are not fossil fuels and can be made using sustainable processes. These fuels come in different forms, such as biodiesel and treated vegetable oil and may form part of a carbon 'offset' strategy. The emission profile for Hydrogenated Vegetable Oil (HVO) is circa 90% lower than that of diesel. HVO is an example of what some people consider a 'transition' approach, allowing vessels to continue fishing while preparing for a move to zero carbon fuel such as hydrogen.

Hydrogen

Hydrogen burns with zero carbon emissions. However, generating hydrogen does require significant energy and may generate emissions. There is a concept called “Green Hydrogen” which aims to co-locate hydrogen production with renewable energy sources such as wind power. Hydrogen is generally considered to have major potential in terms of powering the Irish fishing fleet in the future.

Ammonia

Ammonia is currently used in the refrigeration systems of some Irish fishing vessels (as R717). Like hydrogen, ammonia has some potential for powering fishing vessels in the future. However, infrastructural and safety aspects will need to be addressed. Like hydrogen, ammonia can be made using clean energy and in turn be used to power vessels.

Vessel Design

Vessel design carbon reduction opportunities are mainly applicable to new builds and will therefore take time to implement. The MDV1, a Dutch prototype twin-rig stern trawler, was designed through a collaborative project involving fishing and shipbuilding companies in the Netherlands. The build centred around a highly innovative vessel incorporating multiple efficiency features. The project sought efficiency improvements in hull design, propulsion system, fishing method and even power consumption on board. A 60% emissions reduction is reported because of these design innovations.

The hull is a wedge shape in planform: a nearly vertical narrow bow, a full body amidships and a wide and relatively flat aft ship, which performed the best in various wave conditions. The vessel was completed in 2015 with a length of 30 m, 8.6 m beam, depth to main deck of 5.87 m and a 4.5 m draught. For comparison, this equates to a depth/length ratio of 19.5%, similar to newer vessels in the Irish and UK fleets. The MDV’s propulsion system has a combined diesel-electric power supply using two generators: a large, 500 kW generator for when the boat is lightest during transit and fishing, and a smaller 117 kW generator used for bringing the boat slowly back to shore with a heavy load of fish. It also has a large, three meter-wide, slow-moving propeller rather than a smaller one with higher rpm, which is less efficient at generating forward thrust.

BIM analysis shows that 79% of Irish flagged fishing vessels are purchased from other European fleets and these are at least 10 years old when purchased. The acquired vessels are replaced in the originating fleets by new builds. 50% of the Irish fleet above 12 m have a remnant life of less than 13 years implying a significant requirement to replenish the fleet over the next decade. Over the previous decades, the efficiency of vessels at 10 years was comparable to that of a new-build of the same type, size, and power. This will not be the case for vessels built over the next decade as propulsion technologies and improved hull designs will deliver vessels with significantly improved efficiency. Considering this, the Irish fleet could be at a significant disadvantage from an emissions perspective if the historical pattern of fleet replenishment by existing vessels from other European fleets continues.

Section 5:
Aquaculture Carbon Footprint (overview)

Key points

- The Irish aquaculture sector is a low GHG emission sector. The sector contributes 16.5% of total seafood GHG emissions and 0.23% of emissions compared to agriculture (2017-2019 average).
- Shellfish and seaweed aquaculture have exceptionally low carbon footprints The GHG emissions for rope grown mussel, oyster and bottom grown mussel production are 107 kg CO_2 eq./tonne, 235 kg CO_2 eq./tonne and 824 kg CO_2 eq./tonne respectively.
- Some research suggests that shellfish and seaweed aquaculture may be considered to have a negative carbon footprint insofar as these species absorb more carbon than they release.
- Ireland is the largest producer of organic salmon in the world and Irish farmed salmon emits 3.88 kg CO_2 eq./kg of salmon produced. This is at the low end of animal food production.
- For salmon aquaculture, salmon feed is the main contributor to greenhouse gas emissions accounting for 58% of emissions to farm gate.

The GHG emissions for the Irish aquaculture sector for the years 2017 – 2019 are outlined in Table 5.

Table 5: Average tonnes CO_2 eq. emitted per species farmed in Ireland. GWP refers to the global warming potential associated with an activity – it is an interchangeable term for GHG emissions.

Irish Aquaculture (2017-2019)	GWP (kg CO_2 eq./ tonne produced)	GHG Emissions per Year per Segment		
Species	**-**	**2017**	**2018**	**2019**
Farmed Salmon	3,881.0	71,185.3	46,509.9	43,983.4
Salmon Hatchery	1,001.3	545.7	256.3	400.5
Rope Grown Mussels	107.4	921.7	1,024.7	1,123.4
Trestle Grown Oysters	235.3	2,350.6	2,399.1	2,329.2
Bottom Grown Mussels	823.9	6,171.8	3,869.9	4,032.2
Other Bottom Bivalves	823.9	198.6	206.0	210.9
Other Finfish	4,546.6	2,941.6	2,532.5	2,764.3
Other Minor Cultures	-	-	-	-
Total	**-**	**84,315.4**	**56,798.3**	**54,843.9**

The average carbon footprint for Irish aquaculture between 2017-2019, was 65,319 tCO_2 eq. These emissions include farmed salmon (including the hatchery stage) and the shellfish growing sector.

Overview

Aquaculture in Ireland

Aquaculture output between 2010-2019 has ranged from 30,000 to 50,000 metric tonnes with 42,623 t produced in 2021. It remains mainly export-driven, marine-based, with a smaller land-based, freshwater aquaculture sector. Fluctuation in production value over this period is predominately due to production variations for salmon sea-farms, and to a lesser extent, the volume of bottom grown mussels produced. Overall, production value has seen a net gain from under €100 million in 2009 to €173 million in 2019.

	2017	2018	2019	2020	2021
Penned Salmon	18,342	11,984	11,333	12,870	12,844
Rope Mussel	8,582	9,541	10,460	10,375	11,575
Farmed Oyster	9,990	10,196	9,899	8,763	10,624
Bottom Mussel	7,491	4,697	4,894	4,354	5,865
Other Finfish	647	557	608	604	537
Salmon Hatchery	545	256	400	462	522
Other Bottom Bivalves	241	250	256	233	440
Other Minor Cultures	96	97	73	75	215
National Total	45,934	37,577	37,922	37,735	42,623

Figure 4: Irish Aquaculture Production (2017-2021)

The majority (97% by volume) of Irish aquaculture is comprised of four main species group/production systems (2021 production data):

Salmon (c 13,000t / 31%):
Salmon aquaculture requires high levels of inputs (e.g., feed), animal husbandry and is conducted by a number of large companies. These farms are serviced by relatively large work boats delivering feed as well as personnel for net changes and supporting stocking/harvesting operations. There is also a land-based hatchery and smolt production stage.

Oysters (c. 10,600t / 25%):
Pacific oyster aquaculture is conducted in the inter-tidal zone. As well as small inshore outboard engine boats, there is continuous husbandry during spring tides both on the shore and in the associated land-based facility, mainly with tractors to sort, clean, grade and harvest oysters as they grow.

Rope mussels (c. 11,800t / 27%):
Rope mussels are sub-tidal, and grown, using ropes suspended in the water column. They require vessel support for routine husbandry, grading and harvesting.

Bottom-grown mussels (c. 5,800t / 14%):
Bottom-grown mussels are fished by bottom dredges in natural seed mussel areas and are then re-laid in defined, licensed aquaculture sites.

In addition to the above, there are a number of smaller aquaculture segments including inland trout farming (<2%), land-based shellfish in tanks (c. 1%) and sea-grown seaweed (<1%).

Contribution of Aquaculture to Greenhouse Gas Emissions

The Irish aquaculture sector is a low GHG emission sector. The sector contributes 16.5% of total seafood GHG emissions and 0.23% of national farm emissions. A recent study (MacLeod *et al.*, 2020) estimated that global aquaculture accounted for approximately 0.49% of anthropogenic GHG emissions in 2017. They consider that these modest emissions reflect the relatively low emissions intensity of aquaculture compared to cattle farming. This is due largely to the absence of enteric methane in aquaculture combined with the high fertility and highly efficient feed conversion ratios of finfish and shellfish.

Aquaculture and Climate Change in Ireland

The impacts of climate change for Irish aquaculture will be significant. The changing marine environment will impact Irish aquaculture and pose a variety of future challenges such as altered shell development, changes to shellfish seed recruitment, altered disease, parasite, and invasive species profiles. Research suggests that warmer waters in Ireland will increase physiological stress on farmed salmon and may lead to sub optimal growth. Extreme weather events will also impact on aquaculture activities and lead to reduced operational life spans of equipment and goods. Due to low emissions from the sectors, its contribution to climate action can be considered to be very low, particularly when compared with other higher emission economic activities.

While aquaculture activities emit GHGs, emerging research suggests that it is possible for some segments of the aquaculture sector to absorb more carbon than they emit (i.e., act as a carbon sink). These segments comprise lower trophic species and current research indicates that molluscs (e.g., mussels and oysters) are amongst the lowest emitters of GHGs (Hilborn *et al.*, 2018; MacLeod *et al.*, 2020; Suplicy, 2020), while other studies document a number of ecosystem services (Van der Schatte Olivier *et al.*, 2020, Custódio *et al.*, 2020), through their ability to sequester carbon through the production of geologically stable calcium carbonate shells (Smaal *et al.*, 2019). The cultivation and harvesting of seaweeds can also play a role in carbon sequestration and the reduction of GHG emissions (Chung *et al.*, 2011). As well as sequestering carbon, seaweed can absorb nutrients, offering the potential for remediation services in areas adjacent to terrestrial nutrient run-off and in Integrated Multi-Trophic Aquaculture (IMTA) where seaweed farming is co-located with mussel and salmon farming activity.

Seaweed aquaculture, in particular, is a form of aquaculture that is seen as a nature-based solution that aligns with emerging business models such as blue natural capital financing, blue investments and blue bonds which aim to support investments that promote ecosystem services, conservation and protect the marine environment.

Scoping

Previous LCA Results

This section summarises the results of published LCA studies of the main three aquaculture systems that are found in Ireland (Tables 6 and 7). Although direct comparisons between LCA studies are difficult due to the variation in methodology and the associated assumptions made, they help to give perspective to the results obtained.

Table 6: Summary of previous LCA studies on aquaculture.

Species	kg CO_2 eq./t live weight	Source	Location
Atlantic Salmon Farming	1,200 – 2,700	Pelletier *et al.*, 2007	Canada
	1,790	Pelletier *et al.*, 2009	Norway
	2,000	Winther *et al.*, 2009	Norway
	2,117	Boissey *et al.*, 2011	France
	2,600	Ytrestøyl, *et al.*, 2011	Norway
	2,900 – 6,300	Winther *et al.*, 2020	Norway
	3,100	Yngvadóttir *et al.*, 2013	Iceland
	3,270	Pelletier *et al.*, 2009	UK
	3,390	Liu *et al.*, 2016	Norway
	5,065	Bruguera *et al.*, undated	USA
	5,100	Bjorndal *et al.*, 2018	RAS in Norway
	9,320	White, 2013	Tasmania
	12,800	Parker, 2018	Tasmania
Rope Mussels	5.9 – 281	Runesson, 2020	Sweden
	86	BIM Beara Seafoods Report, 2016	Ireland, cradle to factory gate
	168.7	Henricksson and Stahle, 2019	Sweden
	252	Meyhoff-Fry, 2012	Scotland (no depuration)
Bouchot Mussels	352	Aubin *et al.*, 2018	France
Pacific Oysters	1,281	Meyhoff-Fry, 2012	Scotland, depurated oysters
Basket-grown Oysters	1,850	Tamburini *et al.*, 2020	Italy, local seed

Salmon

Key points
Salmon Farming Emissions

- Irish farmed salmon is grown to an organic standard and can be considered to be a low carbon food source.
- Salmon feed production accounts for the majority of GHG emissions associated with salmon production.
- Over the past two decades ingredients for salmon feed have significantly reduced the quantities of marine sourced proteins used. This has been replaced with plant proteins that are sourced from within the EU.
- The marginally higher carbon emissions for organic salmon farming compared to conventional non-organic production is largely the result of a lower scale of production in Ireland.

One of the earliest LCAs on Atlantic salmon production was Pelletier *et al.*, (2009). The authors of this study examined the GHG emissions from various salmon farming countries around the world. The emissions varied from 1,790 kg CO_2 eq./t live weight for Norway to 3,270 kg CO_2 eq./t live weight for the UK. In all cases, feed production dominated GWP figures (94%), with farm-level energy usage and smolt production making up the balance. Pelletier *et al., (2009)* included feed transport (e.g., 321.7 t-km for the UK) in their calculations but did not include the GWP of operational wastes such as the transportation and rendering of fish mortalities.

Winther *et al.*, (2009), estimate the GWP for Norwegian salmon as 2,000 kg CO_2 eq./ t live weight. They identified that 75% of GWP arose from feed production and use. Liu *et al.*, (2016) estimated a higher carbon footprint for Norwegian salmon at 3,390 kg CO_2 eq./t, of which 94.6% was for feed production. In their more recent update (Winther *et al.*, 2020), they estimate that this varies between 2,900 and 6,300 kg CO_2 eq./t based on differences in the economic FCR (eFCR), the sourcing of soy for feed and energy use, with a headline figure of around 5,200 kg CO_2 eq./ t (see Section 4.1 in Winther *et al.*, 2020). Ytrestøyl, *et al.*, 2011 estimated an overall figure of 2,600 kg CO_2 eq. /t for salmon farming in Norway, of which 96% was related to feed production.

White (2013) examined the GWP of salmon farming in Tasmania, estimating emissions to be 9,150 kg CO_2 eq./t, of which 94% was due to feed production. The high contribution of feed production was mainly attributed to the higher inclusion of terrestrial animal proteins and oils when compared to other major salmon producing nations (e.g., UK, Norway, Canada and Chile) thereby increasing GHG emissions. A more recent study on Tasmanian salmon farming (Parker, 2018), estimated the GWP per tonne of salmon to farmgate as 12,800 kg CO_2 eq. A similar level of feed related GWP (93%) was observed by White (2013). The use of animal proteins and by-products (i.e., poultry meal and oil, blood and mammalian meal) in the feed accounted for 70% of the final GWP.

The Norwegian and UK producers did not use terrestrial animal proteins in their salmon feed on account of regulations prohibiting the use of these materials, whilst the Chilean and Canadian feeds included 15 and 20 percent respectively, all of which came from poultry by-products (Pelletier *et al.*, 2009). This was in contrast to the Tasmanian industry that used materials sourced from both poultry (23%) and mammalian food production systems (14%). Bruguera *et al.*, (undated) have a higher figure of 5,065 kg CO_2 eq./t for farmed salmon, of which 43.4% is from feed, with processing and packaging 39.5%. Newton and Little (2018) demonstrate that terrestrial feed stuffs such as maize gluten meal have a GWP of over 10,000 kg CO_2 eq./ t, whilst soybean meal and fish meal are relatively low at c. 1,500 kg CO_2 eq./ t and c. 1,000 kg CO_2 eq./t respectively.

The results of the above LCAs suggests that the composition of feed is key to determining the final GWP of the final salmon product.

There has been much interest in the role and development of Recirculating Aquaculture Systems (RAS) for part and full cycle production of Atlantic salmon (i.e., to smolt stage and harvest weight). These systems have advantages over open systems in that they allow greater control and treatment of biological fish wastes (reducing the potential of local eutrophication), reductions in the amount of water used for production and reduced interactions with wild conspecifics. While RAS offers advantages in some areas of concern from stakeholders, there is a need to assess the performance of such systems under an LCA framework to ensure that the most environmentally informed/conscious decisions are made. There are a small number of LCA studies on RAS in general and even fewer on Atlantic salmon production (LCAs on RAS for trout culture have been carried out since the early 2010s) (Table 8). One of the more recent studies on salmon RAS in China estimated that the GWP per tonne of salmon may be as high as 16.7 tonnes of CO_2 eq. (Song *et al.*, 2019). A Canadian study on Chinook salmon in a quasi-RAS (a Solid Walled Aquaculture System (SWAS)), reported a GWP of 3.9 tonnes of CO_2 eq. per tonne of salmon to farm gate. A study from 2009, comparing alternative aquaculture systems assessed the environmental performance of a conventional net pen, a SWAS, a marine flow through system (FTS) and freshwater RAS. Energy use for pumps and treatment systems can account for 37 – 84% of GWP of fish produced in RAS and 23 – 82% of energy demand, however water use in these systems is greatly reduced and can reduce the environmental impact of the activity in areas such as eutrophication and acidification potential as well as land or surface. In order to improve the performance of RAS, improvements in energy efficiency are necessary (Winther *et al.*, 2019).

Table 7: Global warming potential and energy demand of selected RAS studies from around the world.

Study	Aquaculture System	Species	GWP (kg CO_2 eq./t)	Energy Demand (MJ)
Ayer and Tyedmers (2009)	Net-pen	Atlantic salmon	2,073	26,900
	SWAS	Atlantic salmon	1,900	32,800
	Marine FTS	Atlantic salmon	2,770	97,900
	Freshwater RAS	Arctic char	28,200	353,000
Aubin *et al.*, (2009)	Net-pen	Sea bass	163	9,191
	FTS	Rainbow trout	406	37,132
	RAS	Turbot	3,670	290,985
Wilfart *et al.*, (2013)	RAS	Atlantic salmon	417	55,530
	RAS	Turbot	3,670	250,010
McGrath *et al.*, (2015)	SWAS	Chinook salmon	3,874	91,600
Song *et al.*, (2019)	RAS	Atlantic salmon	16,747	203,257

Based on the literature reviewed, the emissions associated with the production of Irish organic salmon are in the middle to lower end of the GWP estimates. For further discussion on this topic, please see Salmon LCA analysis in Section 6 of this document.

Mussels

Key points

- The mussel growing sector contributes less than 1% towards Irish seafood GHG emissions.
- The GHG emissions for rope mussel production are low at 107 kg CO_2 eq./t. This is the lowest emission seafood within this study.
- Carbon and nutrient sequestration are a key aspect of this industry. Current LCA methodologies don't take carbon sequestration and positive biodiversity effects of shellfish aquaculture into account.
- BIM through the EMFF funded Knowledge Gateway Scheme has invested in research of the ecosystem services that shellfish aquaculture can provide.

Figure 5: Mussel production using suspended culture method.

In Ireland, blue mussels are cultivated using two techniques. One via floating barrels and suspended ropes (rope mussels) and the other whereby mussel seed is moved to the seabed for growing (bottom mussels). Both mussel cultivation methods are discussed below.

Rope Mussels

For rope mussels, the following LCA and carbon footprint studies are of interest:

Meyhoff-Fry (2012) examined the GHG emissions from a sample of Scottish mussel farms which contributed 23% of total Scottish mussel production. This study looked at mussels grown using the surface barrel/longline method. This study found that fuel dominated the carbon footprint, despite the inclusion of material inputs including ropes, buoys and pegs. Runesson *et al.*, (2020) recalculated the results of eight separate LCA studies into a common functional unit, updating them as required to use more recent coefficients and calculation methods, and standardise the system boundaries as Cradle to Gate. In their analysis the figure calculated by Meyhoff-Fry (2012) became 110.4 kg CO_2 eq./t while Henrickson and Sthale (2019) became 129.6 kg CO_2 eq./t. A previous BIM study estimated a GWP was 86 kg CO_2 eq./ t mussels harvested. Of this, 72% was related to fuels and 28% to materials.

In summary, the above research shows that the suspended culture of mussels is a low carbon emitting sector. GHG emissions for this sector are mainly related to the fuel used to power work boats.

Seabed Mussels

The Irish bottom grown mussel industry produced 5,800 tonnes of mussels in 2021. Wexford Harbour and Carlingford Lough representing 75% accounted for 75% of the overall production, with Castlemaine Harbour and Lough Foyle contributing to the rest. The activity is similar to the one taking place in The Netherlands which consists invovles collecting wild mussel seed from subtidal areas and transplanting this seed into shallow bays for on-growing for between 1 to 2 years, depending on the productivity of the bay, until harvesting. In Ireland, seed transplanting takes place on neap tides, in late summer / early autumn. All seed beds are situated close to shore (within 5 Nautical miles) in a depth ranging from 10 to 25 meters mostly between Rosslare to Wicklow Head with some local settlement in Castlemaine Harbour. Both seed mussel transplanting, and harvesting is carried out using flat bottom dredgers ranging from 24 m to 45 m and deploying 2 to 4 dredges from boom cranes similar to beam trawlers. In Castlemaine harbour, some smaller producers use 5 metre fibre glass punts.

The current fleet of larger mussel dredgers accounts for 18 vessels divided between the production bays. Over 90% of Irish seabed mussels are exported as live mussels to the Dutch and French markets and depuration takes place on arrival.

The majority of the fuel(diesel) consumption takes places during the seed mussel transplanting season with vessels travelling to reach and fish on seed mussel beds. During the on-growing phase, vessels are used for monitoring stock and predator removal, and eventual harvesting. From a 'fleet profile' viewpoint, most vessels are over 20 years old, the eldest vessel was built in the mid-1970s and the most recent launched in 2006. Diesel engines range in size from 335 kW to 734kW with auxiliary generators up to 515 kVA and emergency gensets (30 kVA). Other sources of potential GHG emissions are engine oil, hydraulic oil, mechanical grease, paint (including anti-fouling) and the use of various vehicles on the quayside.

Oysters

Key points

- The oyster growing sector contributes less than 1% of Irish seafood GHG emissions.
- The GHG emissions for oyster production are low at 235.3 kg CO_2 eq./t.
- Most Irish grown oysters are exported to European and Asian markets. Therefore, mode of transport is of high significance for post-harvest emissions.

Oyster production in Ireland is predominantly carried out using trestle and bags. Annually, Pacific oyster production is between 8,000 – 10,000 tonnes. In 2021, production was estimated to be 10,624 tonnes. The key production areas for oyster production are generally concentrated in the Southeast and Northwest of the country. There are only a handful of studies looking at the CF or GHG emissions of Pacific oyster production, with most of the current body of research on bivalves focusing on Blue mussel and Mediterranean mussels.

One of the earliest and most widely cited studies on the carbon footprint of oyster production is Fry-Mehoff *et al.*, (2012), who applied the PAS 2050-2 methodology to the Scottish oyster sector. The study focused on the GWP under a cradle to gate boundary. Interestingly, the authors also estimated the carbon sequestration potential of oyster production. The authors estimated that the GWP for 1 tonne of oysters was 1,281 kg CO_2 eq. The sites that contributed data to the study represented 37% of Scottish oyster production at the time. Most of emissions originated from electricity or fuel use. Electricity for sea water pumps and grading of the stock accounted for 44% (562 kg CO_2 e/t) of GWP. Fuel use in tractors, machinery and generators was estimated as 13% of total GWP (165 kg CO_2eq./t.

Using shell to meat ratios and losses reported by the site operators, the authors of the study estimated that 441 kg CO_2 eq. were sequestered per tonne of oysters produced, thereby reducing the total carbon footprint to a lower value.

Tamburini *et al.*, (2019), carried out a LCA of oyster production in Northern Italy. They used a cradle-farm gate approach to estimate the environmental impact of 1 kg of fresh oysters.

The culture system is different to that used in Ireland (trestles and bags), as they use a long line system, where the oysters are suspended off the seabed in a series of baskets. The authors of the study used a different impact assessment methodology which makes it difficult to compare the GWP of Italian oyster production against others. However, they do report a figure of 1,850 kg CO_2 eq./t, if the seed used in the hatchery was sourced locally. This value is at the higher end of the values reported for Pacific oyster production.

Other Cultures

Other forms of aquaculture practiced in Ireland include the freshwater growing of rainbow trout, the European perch, and the hatchery stage of Atlantic salmon smolt production. Other marine aquaculture activities include the production of seaweeds and invertebrates such as abalone. In the absence of a calculated Irish trout GWP factor, a GWP factor from an LCA study of Italian rainbow trout (Maiolo, 2021) covering fish feed and fish grow-out is used as a proxy to calculate 'Other Finfish GHG' emissions. A GWP factor of zero has been applied to 'Other Minor Cultures' ('seaweed and minor shellfish') due to the absence of a GWP factor and their low tonnage (<100 tonnes/annum average 2017-2019). Although seaweed does not feature highly in this report, it will play a role in carbon sequestration and eutrophication mitigation in the future, as this segment emerges and increases output.

Section 6:
Aquaculture LCA Results and Analysis

Key points
Salmon Life Cycle Assessment

- Salmon feed accounts for 58% of GHG emissions to farm gate.
- 75% of GHG emissions occur at sea stage and 25% at land stage.
- Transport accounts for circa 13% of GHG emissions. This includes the transport of feed and the movement of harvested fish (this figure does not include transport to market).
- The GWP of Irish farmed organic salmon is 3,881 kg CO_2 eq./t.

Results

The calculated GWP of farmed salmon is 3,881 kg CO_2 eq./tonne and can be found in the table below (Table 9). Two LCA approaches were adopted during this study as indicated below:

A. Basic LCA:
The basic LCA contains the elements included in most classic 'farm gate' salmon LCAs conducted to date, including production of the feed, on-farm energy and transportation, and consumables used (vaccines, therapeutants as well as equipment replacement).

B. Extended LCA:
The extended LCA adds elements not always included in 'farm gate' salmon farm LCAs, such as feed transportation from manufacturer to site as well as the transport of mortalities to their disposal site and the method of their disposal.

Table 9: Global Warming Potential of farmed salmon (kg CO_2 eq./tonne of salmon).

Basic LCA					
Process	**Input**	**Impact (GWP)**	**Total**	**% basic**	**% basic and extended**
Feed	Land-based production (UP 2)	51.2	2,263	58%	39.1%
	Sea-based production (UP 3)	2,211.9			
Energy	Land-based production (UP 2)	1,001.3	1,044	27%	18.1%
	Sea-based production (UP 3)	42.7			
Transport	Diesel vehicles / vessels	490.4	500	13%	8.6%
	Petrol vehicles / vessels	9.2			
Consumables (inc. equipment and packaging)	Land-based production (UP 2)	0.3	74	2%	1.3%
	Sea-based production (UP 3)	66.6			
	Harvesting (UP 4)	7.3			
Totals			**3,881**	**100%**	**67.1%**

Extended LCA					
Process	**Input**	**Impact (GWP)**	**Total**	**% basic**	**% basic and extended**
Feed transport	Land-based production (UP 2)	47.9	1,224	N/A	21.2%
	Sea-based production (UP 3)	1,176.5			
Mortality transport	Land-based production (UP 2)	1.3	62	N/A	1.1%
	Sea-based production (UP 3)	61.1			
Mortality disposal	Land-based production (UP 2)	12.3	614	N/A	10.6%
	Sea-based production (UP 3)	601.6			
Totals			**1,900**	**N/A**	**32.9%**

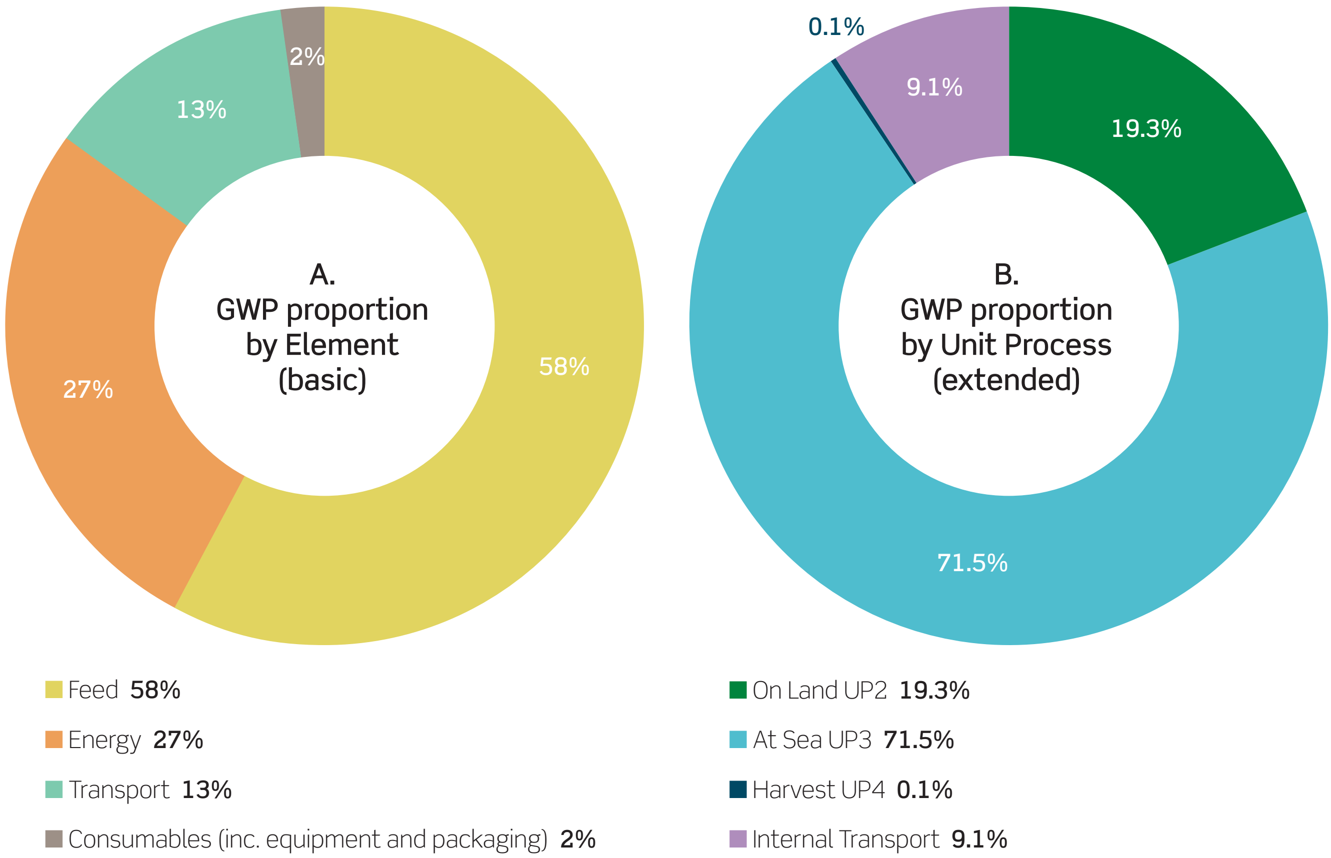


Figure 6: Distribution of GWP of salmon production by (A) element and (B) Unit Process.

Figure 6 above shows that over 71% of the GWP is produced during the sea stage of the production cycle (including feed and mortalities transport) under the extended LCA scenario. This is unsurprising, given that this is where the majority of feed is consumed. The land-based smolt production accounts for just under 20% and internal transport (unallocated to sea or land, but likely mainly the former) accounts for just under 10% of the GWP.

Analysis

The basic LCA suggests a GWP of 3,881 kg CO_2 eq./t of live-weight salmon produced at farm gate. This is higher than that reported for Norway (between 1,790 – 2,600 kg CO_2 eq. /t salmon, see Winther *et al.*, in 2009) but lower than the revised figure of around 5,200 kg CO_2 eq./t reported by Winther *et al.*, in 2020. The Irish figures is also higher than that reported for the UK (3,270 kg CO_2 eq./t salmon). The lack of detail of most previous studies makes it difficult to determine where the difference lies, and emphasises the caution required in comparing the results of different LCAs without knowing their precise scope and methodology.

Using the results of the salmon LCA studies from Table 7 (literature review), Irish organic salmon production lies in between the average and median values of that sample. The average GWP for a tonne of salmon, using those studies, is 4,221 kg CO_2 eq. The median value is 3,785 kg CO_2 eq./t. The value for Irish salmon is higher than has been reported by some studies (i.e., Pelletier *et al.*, (2007)) but lower than other European salmon producing countries (i.e., Winther *et al.*, (2019)). The studies used to estimate the average GWP of a tonne of salmon from Table 7, have a relatively high coefficient of variance at 72%. This indicates that there is high level of variability between the GWP associated with a tonne of salmon.

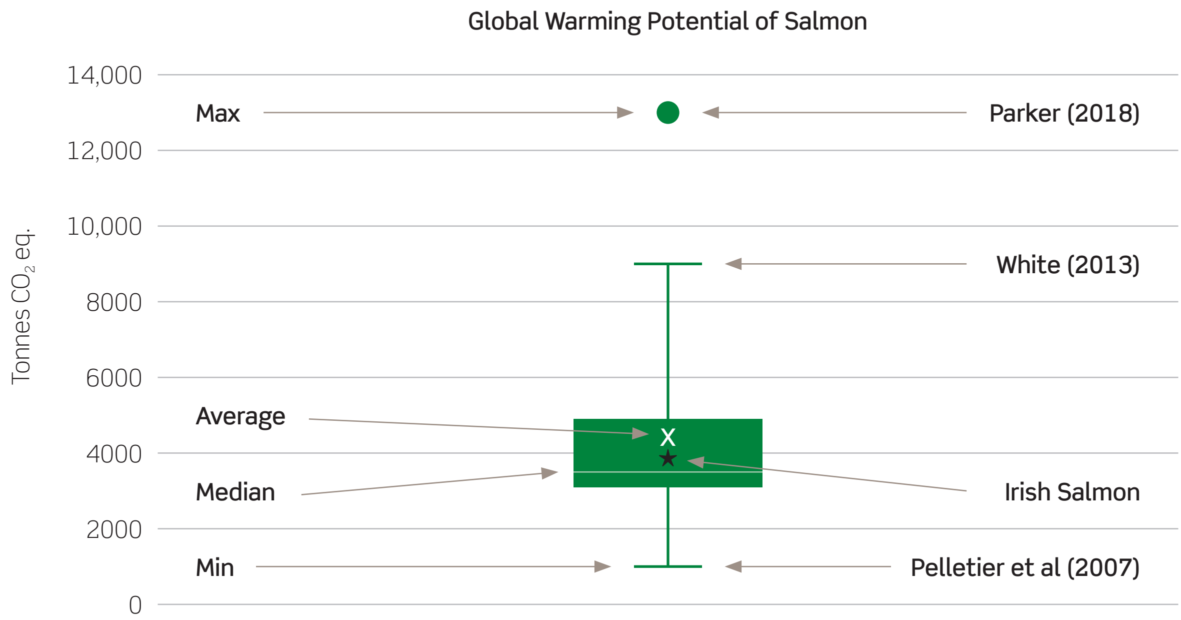


Figure 7: A box and whisker plot of the emission in kg CO_2 eq./tonne of major salmon LCA studies from around the world. Irish salmon production sits between the average and median values of these studies.

Under the basic LCA

- The feed component is relatively low at around 58% compared with most other LCAs which vary from 75% to 95% (see below).

- The organic feeds used by the majority of salmon produced in Ireland are formulated to comply with EU organic legislation. Composed mainly of fish meal trimmings (43.7%), fish oil (17.7%), and organic peas and beans (18.6%). The latter vegetable components tend to have relatively low GWP compared to, for example, maize-based meals. However, trimmings-based meal can have a carbon-footprint up to 41% higher (e.g., 1.054 kg CO_2 eq.) than fishmeal derived from fresh fish (*Peruvian anchoveta*) which has a carbon footprint of 0.624 kg CO_2 eq.). The higher emission for trimmings arises from the low yield and additional energy inputs associated with the refining and transportation of the raw material. It should be noted that over the past two decades ingredients for salmon feed has significantly reduced the quantities of marine sourced components towards the inclusion of plant proteins that are sourced within the EU (see Figure 8 for more detail).

- Energy costs for the land-based production of smolts were high at around 27% of the basic LCA. This study had access to detailed energy consumption data for both UP 2 and UP 3. Electricity is required for production of half year smolts (S0). Fertilised ova are incubated in heated water (8°C) to accelerate hatching. Energy is also required for feeding systems, oxygen monitoring and effluent treatment plants, all of which are run continuously. All land systems and particularly those producing larger fish (to reduce the time in sea) are more energy intensive. This has implications for approaches that hold smolts on land for longer periods (e.g., the so-called 'super smolt approach'), as this is likely to result in a higher GWP, although there are trade-offs in terms of less time at sea to harvest weight, requiring less feed, and less boat time. It should also be noted that in other countries, Scotland for example, smolt grow out takes place in loughs. Irish smolt production takes place in flow through systems, which have limited volumes of water which can be abstracted, requiring them to use liquid oxygen. On the other hand, Scottish juvenile production is often lake based and utilises the ecosystems services of these waterbodies, thereby having a lower carbon footprint for this stage of production when using current LCA methodologies.

- The other significant GWP element was transport. The majority of Irish salmon production is currently supported by diesel vehicles and vessels (89%) with the remainder being kerosene (8%) or petrol (3%). As aquaculture activities mainly take place in rural, coastal regions, vehicles and transportation routes often consist of winding roads, far from centralised facilities such as ports and processing facilities.

Under the extended LCA

- Feed is transported from the Isle of Skye in Scotland via ferry to Foyle Port in Derry, Northern Ireland (367 km) and then distributed to the individual farming sites. This has a considerable GWP element and adds 21% to the basic LCA. This is an improvement on previous routes that tended to be by road from Skye to Stranraer, boat to Larne (723 km) and then by road to the farms. However, when compared to the UK LCA example in Pelletier *et al.*, (2009), where feed transportation was 322 tonne-kilometres (t-km), the current ferry route direct from Skye to Ireland is considerably higher at around 10,000 t-km. This suggests that the lack of a national aquafeed production facility in Ireland has implications for the GWP of the industry.
- Whilst mortality levels contribute to feed used and harvestable biomass loss (see above in the basic LCA analysis), they also contribute to GWP as they require disposal. This has two implications. Firstly, is the method of disposal as depending on the animal by-product category, salmon mortalities have to be incinerated. This incineration of mortalities has a sizeable GWP burden e.g., nearly 11%. Given the emergence of the circular economy as part of national and EU policy, in the near future there will be opportunities to increase the circularity of this lost biomass from salmon aquaculture as animal feed ingredients, fertiliser or fuel for energy production.

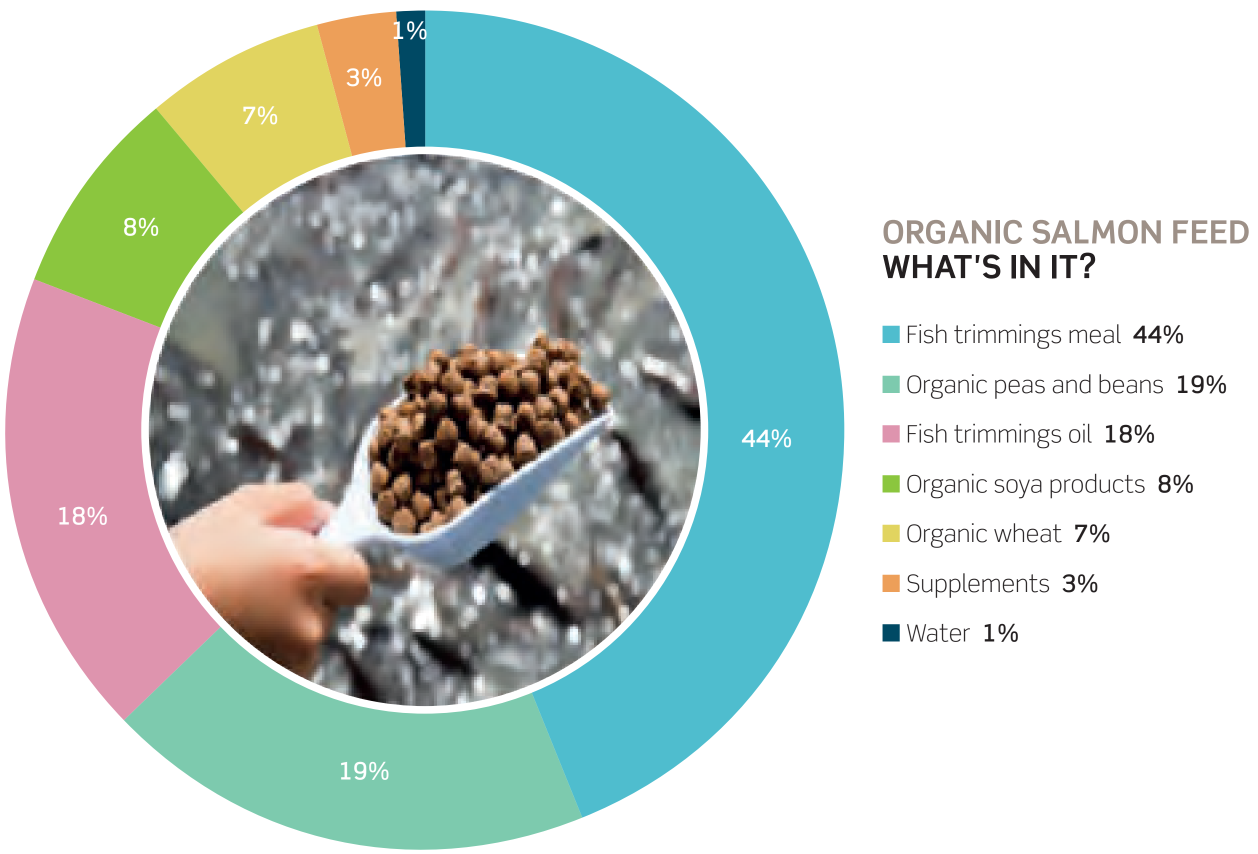


Figure 8: Feed ingredients for production of Irish organic salmon (Source: MOWI Ireland).

The ingredients of salmon feed used in Ireland are show in Figure 8. The higher emissions from producing organic feed can, in part, be explained by the inclusion of fish trimmings in the makeup of this feed. It is important to bear in mind that the alternative to the valorisation of these trimmings for feed (either aquafeed, agriculture or pet food) is that they may instead be sent to waste and their nutritional value not recovered. These processing by-products can often have no value or market for human consumption. By upcycling these nutrients and recovering them as an added value food product it helps to minimise nutrient loss and waste, while also promoting nutrient and resource efficiency. The inclusion of by-products, using nutrient recovery through animal nutrition, can promote a circular economy through reducing the volume of waste streams through adding value. In this regard organic feed production practices can help promote food system circularity.

With the transition to organic aquaculture by the Irish salmon sector, there has been a marked change in the sourcing and transportation requirements of feed and feed ingredients.

Fish meal and oil for organic aquaculture feed can only be sourced from either by-products and trimmings of fish or from sustainably certified fisheries. The bulk of the fish meal and oil used in Irish organic feeds is sourced from trimmings and processed at a fish meal and oil plant in Donegal. These products are then transported to Scotland where they are used in the formulation of organic feeds. Prior to organic standards the sector would have used meal and oil from countries like Peru, Norway and Denmark.

Other ingredients for organic salmon feed are sourced from within Europe, with all of the peas, beans and wheat coming from central Europe (Table 10). Vitamins, minerals and feed premixes (amino-acids, macro-minerals and pigments) coming from the UK or Germany. When compared with other salmon producing countries like Norway and Scotland, Irish organic feeds have a less globalised supply chain. Norway and Scotland source many of their ingredients from countries such as Brazil, Peru and China.

Table 10: The salmon feed ingredients and the countries they are sourced from.

Ingredients	Ireland	Scotland	Norway
Fishmeal and oil	Ireland	Denmark, Peru	Norway, Peru, United States
Peas and Beans	France, Germany, Hungary	Brazil, UK	France, Germany, Austria
Sunflower	-	Ukraine	Argentina, China, Ukraine
Wheat	Ukraine	Germany, France	Netherlands, Belgium, Germany
Guar	-	-	Brazil
Dried distillers grains	-	Scotland	-
Vitamins, minerals, premixes	UK	UK	Norway

Ingredients - Conventional salmon feed (UK)

Fishmeal and oil

Soybean meal

Maize and wheat gluten

Sunflower seed cake

Fava beans, rapeseed oil, whole wheat

Dried distillers grains vitamins and minerals

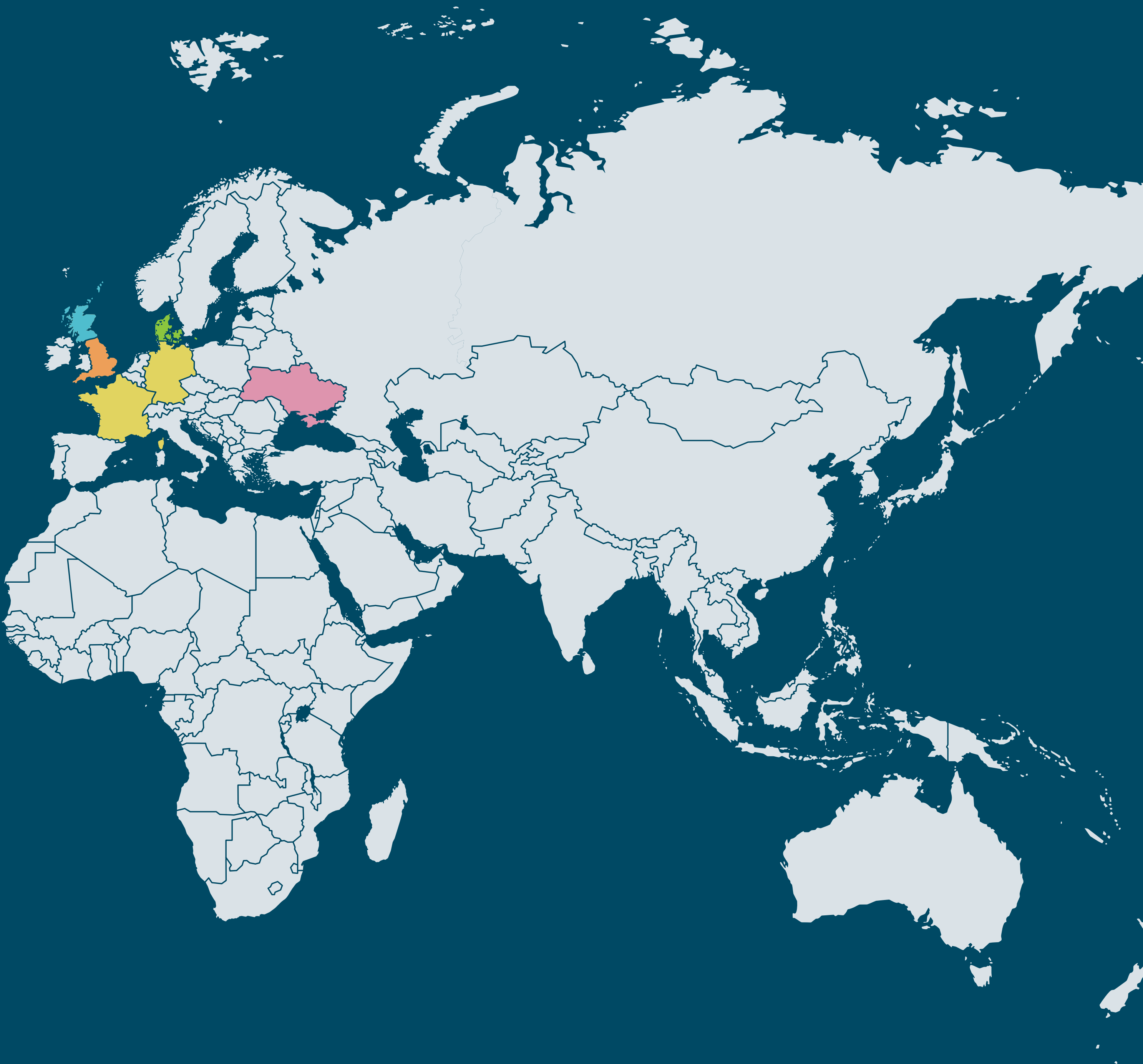


Figure 8: The feed supply chains for European salmon aquaculture feed ingredient (Source: Newton and Little, 2018).

Ingredients - **Organic Salmon Feed Ingredients in Ireland** (100% sourced within Europe)

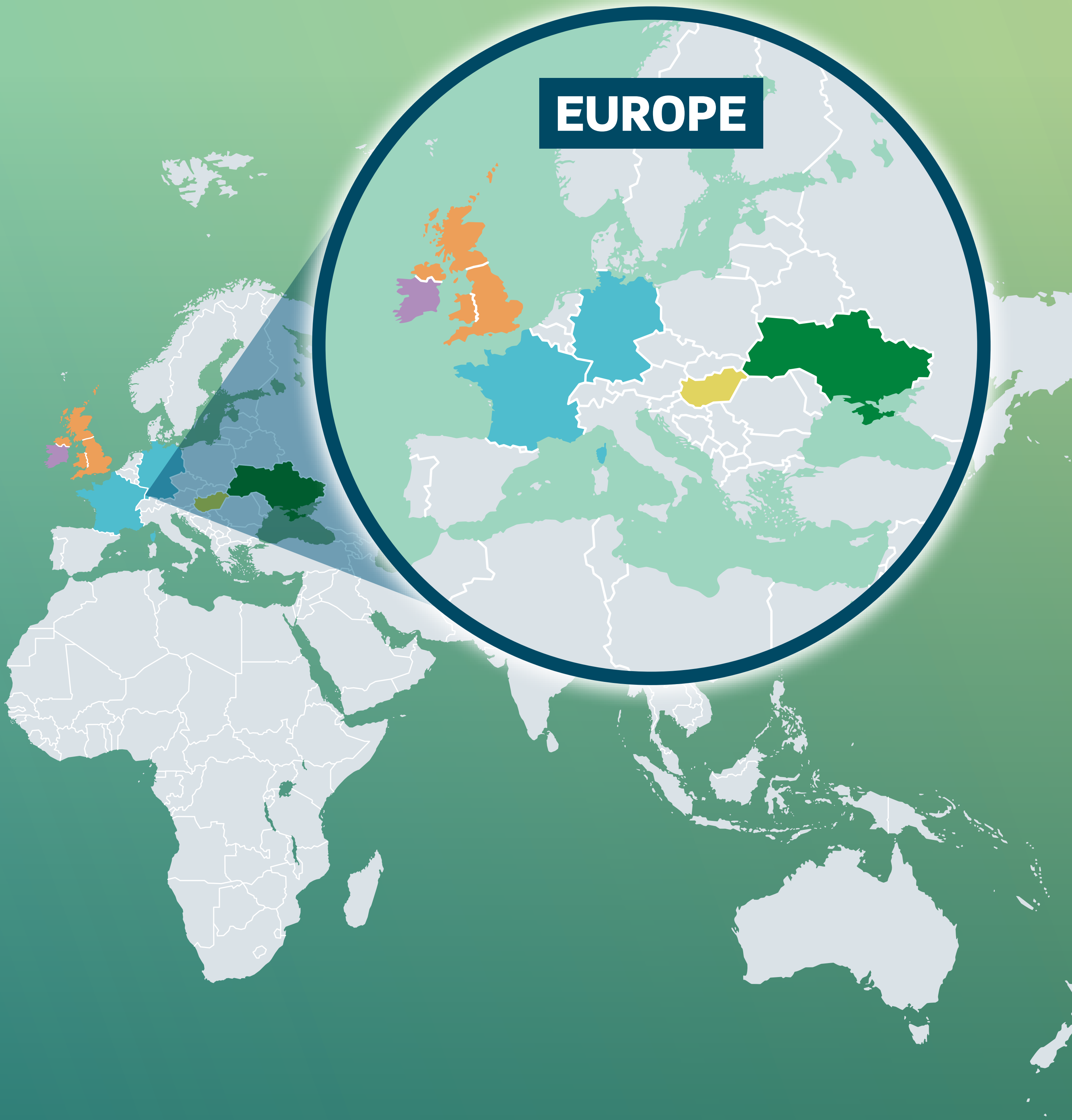
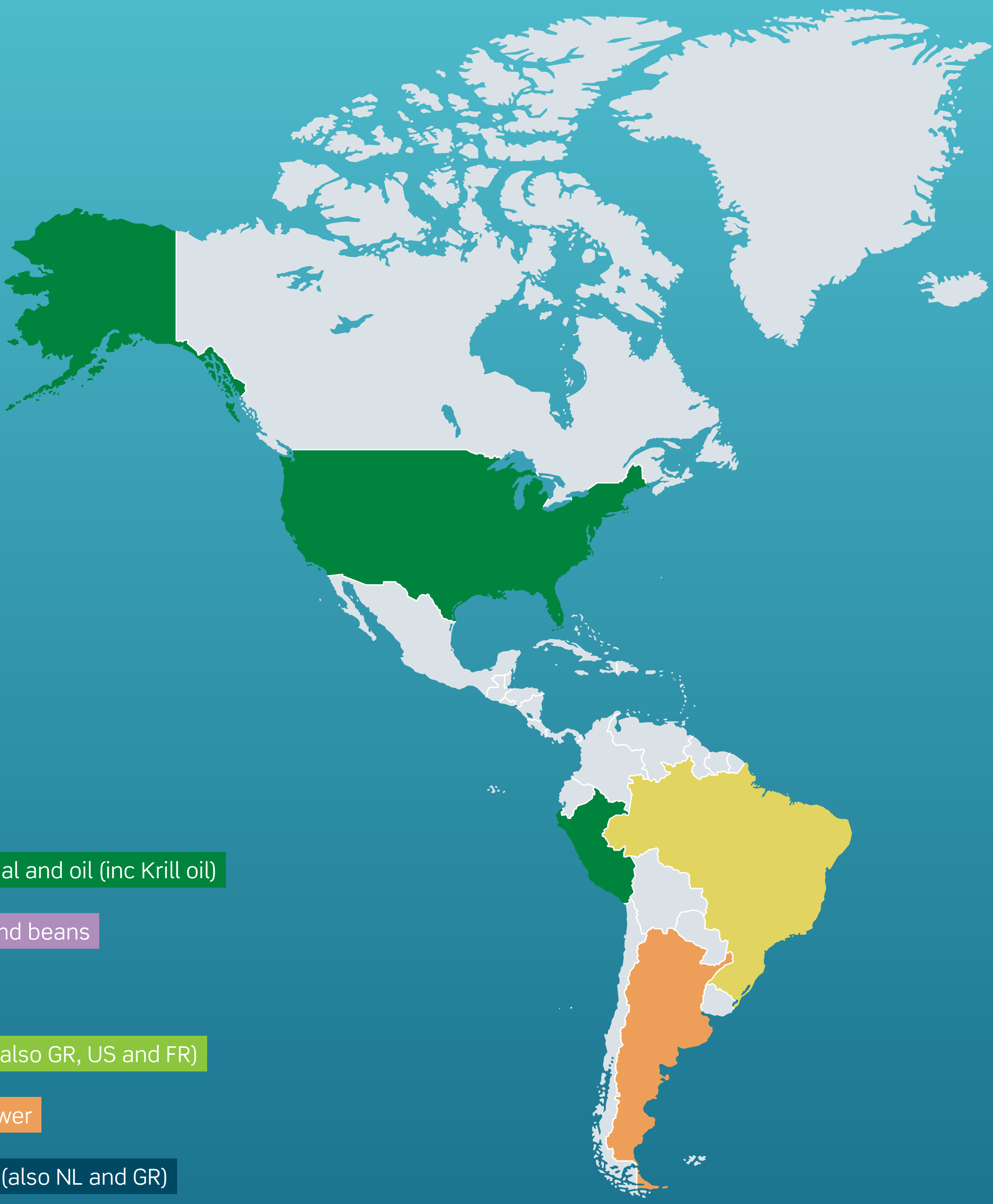


Figure 9: The feed supply chains for European salmon aquaculture feed ingredient.

Ingredients - **Conventional salmon feed** (Norway)



Fishmeal and oil (inc Krill oil)

Peas and beans

Guar

Maize (also GR, US and FR)

Sunflower

Wheat (also NL and GR)

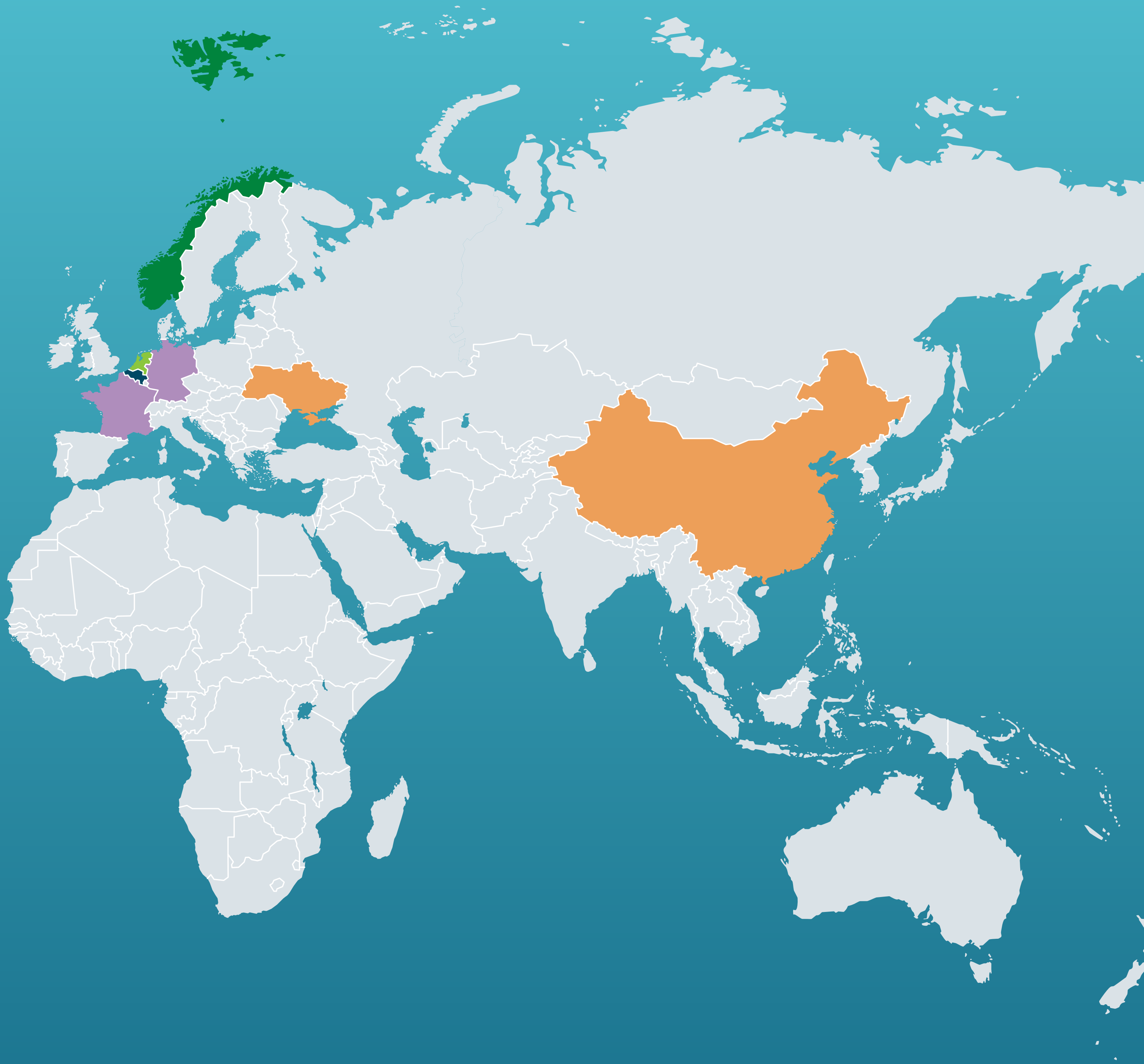


Figure 10: The feed supply chains for European salmon aquaculture feed ingredient (Source: Winther *et al.*, 2020).

The distance that ingredients have to travel to feed mills and from mills to farms is an area which can account for approximately 10% of GWP of feeds. For example, Parker (2018) reported an average distance of 8,800 km for feed ingredients to the feed mills (80% of this distance by sea), with an additional 3,060 km required for transportation to the farms. Newton and Little (2018), estimated that 50% of feed ingredients for Scottish salmon were sourced from South America and that less than 25% originated from in the UK. They also noted that transportation for Scottish salmon was a minor contributor to overall environmental impact but did highlight that much of the impacts for feed ingredients did not occur in Scotland but at a regional scale in the producer countries.

A carbon footprint is only one of the impact categories that is usually included in an LCA of aquaculture and seafood. It is an important one and often forms the basis of a benchmark through which a sector can help to identify environmental hotspots and areas for further and future work. The inclusion of other impact categories such as ecotoxicity potential can help to identify how organic aquaculture can have lower impacts in this category through the lower use of therapeutics and chemical treatments. A number of recent studies have shown that feeds that use high levels of fish trimmings as ingredients, also have lower marine Biotic Resource Use (BRUs) (Ghamkhar & Hick, 2020).

Mitigation Options

Based on the basic and extended LCA calculations, Irish salmon production has a higher GWP than its Norwegian and Scottish (UK) counterparts. This is not surprising, as there is less vertical integration in the sector and it is much smaller in scale e.g., c. 12,000t as opposed to 1,300,000t in Norway and 200,000t in Scotland, with no local feed production. As such the Irish sector does not benefit from the economies of scale, co-location of services and facilities of the other countries. However, due to the constrained nature of the sector, it has a limited sectoral environmental impact in comparison to Norway and Scotland due to the production limitations of the sector. For example, a tonne of Irish salmon emitting 3.9 tCO_2 eq., multiplied by the sectoral output of 12,000 tonnes, puts the sectoral emissions at 46,572 tCO_2 eq. Using the same approach, the sectoral emissions for Norway (using Winther *et al.*, (2020) at 6.3 tCO_2 eq./t and a sectoral output of 1.3 million tonnes, has a GWP of 8,190,000 tCO_2 eq., 176 times greater than the Irish sector. Below we list a series of mitigation options.

- Increased vertical integration and increase sector scale (subject to licencing); The low volume and decentralised nature of the Irish salmon farming sector places limits on the opportunities available to reduce GHG emissions.

- Feed is the main source of GHG emissions for salmon farming. This result is not surprising as, in almost all fed animal systems, feed routinely accounts for a significant portion of environmental impacts. Careful consideration should be given to the economic and environmental costs and benefits of developing domestic aquafeed production capabilities using nationally sourced materials thereby reducing the emissions from transportation in aquafeed supply.

- Transport is a significant source of GHG emissions. Transport of feed and harvested fish and fish mortalities all contribute to transport related GHG emissions. As the economy moves towards electrification in the transport sector, emissions for this aspect of salmon production are set to decrease in the short to medium term.
- Salmon feed used in Ireland is produced to an organic standard with a high level of environmental and process circularity incorporated into its production. The wider environmental performance of organic feed production needs to be fully explored and communicated to consumers and producers.
- Further investigation into energy and nutrient recovery in salmon production is required. For example, energy recovery through increased utilisation of fish wastes (i.e., sludge) through anaerobic digestion and the added value opportunity of the resultant digestate as a fertiliser.
- RAS production of smolts can have higher GHG emissions than conventional salmon production. However, these emissions could be mitigated by local feed sourcing and increased use of renewable energy. An interim alternative to RAS is the use of natural water bodies (i.e., lakes) for smolt production (subject to licencing), similar to the current practice in Scotland. The land-based RAS grow out of salmon is not, at present, seen as a viable way to reduce environmental impact given the high carbon emissions for these closed systems.
- Develop and increase advanced environmental modelling capabilities (i.e., LCA, carbon foot printing, circular economy modelling) to explore strategic scenarios for this sector and the GWP implications of different business strategies. For example, raising post-smolts on land (e.g., so called 'super smolts'), transport/logistics and local feed production.
- Promote and increase the use of clean energy across the production and supply chains. Demonstrate energy saving opportunities, especially for heating and pumping water in land-based production facilities.

    a. Move to hybrid and pure electric propulsion (where possible) at sea. This will require installation of the necessary charging infrastructure over the different farming units.

    b. Further introduction of renewable energy generation (e.g., solar, wind and where possible tidal) and battery storage for remote and sea-based facilities to run feeding systems, electronic monitoring and other electrical systems that currently use diesel or other generators. Barriers to the uptake and implementation of these technologies may exist with licensing and planning requirements. Where these are identified, timely resolutions should be introduced.
- Genetic improvements in stock to improve feed conversion ratio and disease resistance thereby reducing the amount of feed required to grow fish.
- Most (> 95%) Irish grown organic salmon is exported. Consideration should be given to developing domestic markets in order to reduce post-harvest supply chain emissions.
- Investigate the potential of IMTA as a way of reducing GHG emissions (nutrient offset or nutrient balancing) given that lower trophic organisms could be used solely for mitigation purposes or for increasing product offering.

Rope Grown Mussels

Key points

- Emissions from this sector are small and are estimated to be 1,023 tCO_2 eq. on average across 2017-2019.
- Emissions per tonne of mussels are the lowest in the Irish seafood sector at 107.4 kg CO_2 eq./t.
- Diesel use for workboats is a key driver of GHG emissions in mussels. Diesel accounts for close to 90% of emissions for this sector.
- Consumables account for only a small portion of total emissions (less than 10%).
- Carbon sequestration is not considered in current carbon emission and LCA calculation methodologies. Some studies suggest that the inclusion of sequestration could lead to negative emissions for this sector (i.e., mussels may act as a carbon sink).

Results

The GWP of rope grown mussels from Irish farms is shown in Table 11 below. The reference farms for this report produced 23% of Irish mussels during the sample period (2017-2019).

Table 11: Global Warming Potential of rope grown mussels (kg CO_2 eq. /tonne of mussels).

Unit Process	Type	Input	Input	UP Total GWP	%	Total
Production	Fuel	Hydraulic Engine Fuel (Diesel)	52.1	91.86	85.5%	93.1%
		Raft Fuel (Petrol)	9.1			
		Van Fuel (Diesel)	21.9			
		Boat Fuel (Petrol)	6.6			
		Electricity	2.0			
		Natural Gass	0.1			
	Consumables	Raw Cotton Mesh Wrap.	7.6	7.59	7.1%	
	Servicing	Engine Oil	0.2	0.59	0.5%	
		Hull Coat	0.2			
		Hull Coat Paint Emissions	-			
		Antifoul	0.2			
		Antifouling Paint Emissions	-			
		Gearbox Oil	0.0			
Packing	Use and Disposal	Polypropylene Bulk Bags	3.5	7.37	6.9%	6.9%
		Polypropylene Woven Bags	1.4			
	Production	Bag Production	2.5			
Total			**107.4**		**100%**	

Analysis

The LCA suggests a GWP of 107.4 kg CO_2 eq./t. of live-weight mussels produced at farm gate. This is 57.5% lower than the values Meyhoff-Fry (2012) reported for a similar process with no depuration. The Irish figures are in the middle of the range of recalculated values from published LCAs by Runesson (2020).

Fuel and energy accounted for 85.5% of the carbon emissions from the sample mussel farms. This is higher than the reference studies such as Meyhoff-Fry (2012) (energy collectively 55%).

- 46% of the fuel use recorded was in the raft/grading equipment.
- Boat and raft fuel, used to move the raft and for support craft by contrast accounted for just 21% of fuel emissions. There were significant variations between the producers, with one producer emitting CO_2 eq. at four times the rate of another.
- The cotton mesh socking used to contain the mussels while they attach to the new rope after grading is organic and biodegradable, and accounts for 4% of the emissions. There was considerable variation reported in the use of socking with the heaviest user per tonne reporting three times the consumption of the lowest.
- Meyhoff-Fry (2012) included ropes and buoys, but under PAS 2050-2 guidelines these are excluded as each of the reference sites was over ten years in operation and reported no disposal of ropes and floats that failed were repaired. Meyhoff-Fry (2012) also included electricity (13%) and depuration (6.6%) which are not generally a feature on Irish farms. It is also worth noting that in Runesson (2020)'s recalculation, these were also removed, reducing the GWP figure to 110.4kg CO_2 eq./t.

  The other contributor to GWP was production and use of the intermediary packaging when transporting market ready product to the processor. This stage was included as it occurs under the control of the producer on the quay and is the final stage in the farm- gate system boundary. The market ready mussels are packaged in 1 tonne flexible intermediary bulk containers (FIBC) or 60 kg bags, depending on the customers' requirements. Production, use and disposal of these FIBCs and bags accounts for 6% of GHG emissions. The use of FIBCs is more common than the 60kg bags and significantly lowers emissions of the intermediary packaging for transport as less material is required.

Mitigation Options

As 90% of GWP impact for mussels arise from the use of fuel, the mitigation options should be focused in this area.

- Good maintenance and optimisation of equipment for the weight and size of the ropes could result in significant reductions in the energy required to operate them.
- Careful planning of the venture can yield significant improvements on operational efficiency. Selection of sites with close shore access; appropriate mooring, bathymetry and seabed type, and appropriate use of support craft can reduce fuel use and improve the emissions rate without compromising efficacy. For example, two of the sites studied had to travel several kilometres from their base to their lines. To reduce their GWP, these operators should ensure they access their sites using the correct cruising speed, appropriate trim and with an appropriately sized engine.
- Van fuel use could be mitigated through use of a hybrid or electric vehicle lease or purchase in future. Vehicle range would have to be considered given the remote location of some sites and lack of charging infrastructure. Although the current limited availability of utility grade hybrid or electric vehicles also presents a barrier to increased uptake. Alternative fuels for the van fleet could be considered, eg. Biodiesel.
- Ensure reuse of FIBCs (1-tonne bags). These are currently assigned a lifespan of one trip an obvious opportunity is to reuse these highly-durable bags for multiple trips. The farmers noted that this would be the case if the processor was arranging the collection and was thus able to return them, but this was not the case with third-party logistics. A system on the part of the processor to record, store and return bags could result in these being used many times (following circular economy principles). Consideration of the type of bag may also be important, as bags designed to be emptied from the bottom would not need to be cut to release the contents, enabling bags to last longer and therefore using less materials in total.
- The ecosystem services that shellfish aquaculture may provide requires additional research. BIM through the EMFF Knowledge Gateway Scheme has funded a research programme, ShellAqua, which aims to assess the benefits to human wellbeing from healthy ecosystems, supported by the sequestration potential of shellfish aquaculture.

Trestle Grown Oysters

Key points

- Emissions from this sector are small contributing less than 1% towards Irish seafood GHG emissions.
- Emissions per tonne are small – 235.3 kg CO_2 eq. per tonne of oysters.
- Tractor diesel is a key driver of GHG emissions. Diesel accounts for close to 60% of emissions for this sector.
- Carbon sequestration is not considered in current carbon emission and LCA calculation methodologies. However, this may change in the future (i.e., ShellAqua project).
- A significant portion of oyster seed sourcing is from outside the state (France). However, only a small portion of GHG emissions are attributed to seed (6%).

Results

The calculated GWP (in kg CO_2/tonne) of trestle grown oysters from Irish farms is shown in the table below. The reference farms produced 6% of Irish oysters during the sample period (2017-2019).

Table 12: Global Warming Potential of trestle grown oysters (kg CO_2 eq./tonne of oysters).

Process	Input	Average Imapct (GWP)	Total GWP for UP	%
Production	Green Diesel	131.1	131.1	55.7%
	Water for cleaning and other domestic functions	0.0	16.1	6.8%
	Bags Production	15.6		
	Oil and Lubricants (maintenance)	0.5		
Primary Processing (including Depuration)	Seawater	0.0	72.5	30.8%
	UV Bulbs	0.1		
	Electricity	72.5		
Transport	Seed delivery	15.6	15.6	6.6%
Total		**235.3**		**100%**

Analysis

The LCA suggests a GWP of 235.3 kg CO_2 eq. per tonne of live-weight Pacific oysters produced. This is 81.7% less than Meyhoff Fry (2012) found for a similar process with depuration.

- The number of Irish oyster sites sampled was small, therefore care must be taken when scaling up to industry level. Future work in this area will increase the robustness and representativeness of these values.
- Compared to other Irish seafood species LCAs analysed, oysters' GWP per tonne is very low.
- Fuel and energy use account for 86.5% of the total emissions. This is slightly higher than the 72% observed by Meyhoff Fry (2012), but the magnitude of the consumption is more striking, with emissions from fuel in Meyhoff Fry (2012) at 728 kg CO_2 eq./t as opposed to 203.6 kg CO_2 eq./t in this study. The emission rate from fuel is not dissimilar to that in Meyhoff Fry (2012) (165 kg CO_2 eq./t), suggesting that on average the estimated use of machinery has been conservative. In that study electricity use was the largest emitter, but in the Irish instance it is just over half that of diesel. This is partly due to a 22.6% reduction in emission intensity for grid electricity in that time, from 0.49 kg CO_2 eq./kWh in the UK in 2010 to 0.38 kg CO_2 eq./kWh in Ireland in 2018 (mid-point of sample periods).

Over half of the difference is accounted for by their decision to include an amortized value for the production of the trestles, while the rest appears to be due to the lack of information about ties and closures (metal hooks and rubber bands) collected in this study but included by Meyhoff Fry (2012). None of the three sample sites were able to give more than a rough estimate of this so the data was not included. Meyhoff Fry (2012) does however note the huge variability in their data, with one farmer reporting use of 25 times as many ties as the other, so the inclusion of this data is questionable.

- Depuration accounts for a slightly higher proportion of the total than Meyhoff Fry (2012) (31% against 24%), despite one of the Irish producers not depurating their harvest. There was again considerable variability in the Scottish data, and it should be noted that their emissions from depuration are greater than the total Irish emissions. It may be that since the study was completed (2012) the efficiency of pumping systems has improved, or the quality of the water may require longer residence in the tank.

- Fuel consumption in the equipment and vehicles varied considerably, with the highest intensity being 3.6 times the lowest. Information about the extent and proximity of the growing sites to the production facility was not sought but may be useful in further interpreting this, as would analysis of the management options such as the number of times bags were thinned or turned.

Mitigation Options

- Diesel use is the largest contributor to GHG emissions and will need significant focus. Increased use of biofuels and LPG for tractors and site vehicles could offer significant reductions in GHG emissions compared to use of diesel. Additionally, modernisation of the fleet of tractors used in the sector could also reduce emissions. Newer machinery is required to use emission control technologies such as Diesel Particulate Filters (DPF), Selective Catalytic Reduction (SCR), and Exhaust Gas Recirculation (EGR).

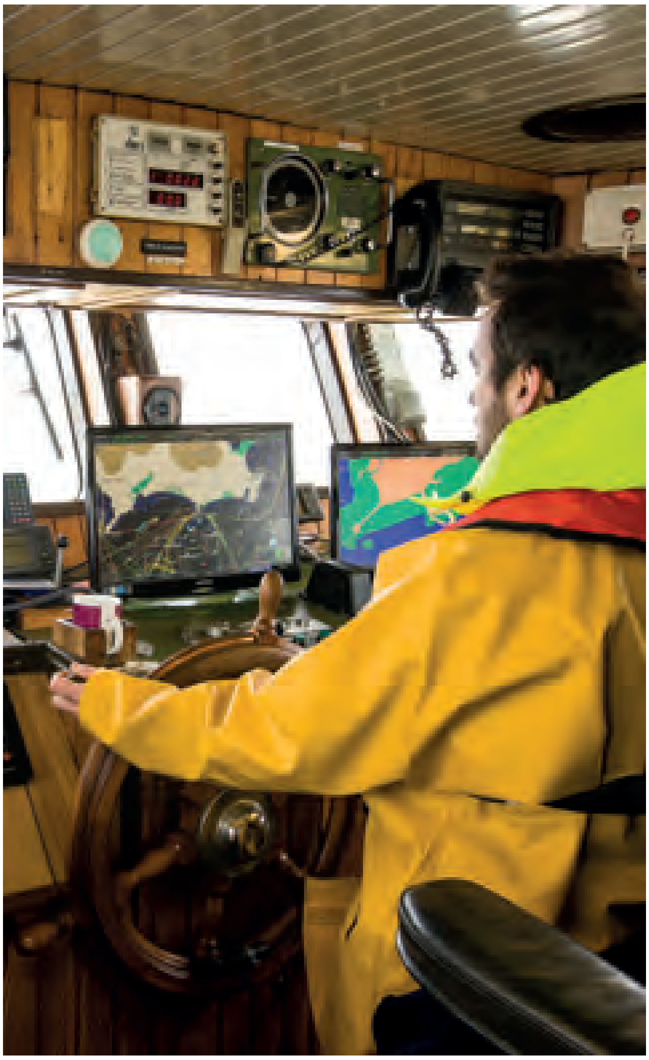
- Improvements in energy efficiency for depuration can be achieved through the use of Variable Speed Drives (VSD) on pumps. In a 2019 study of Irish shellfish depuration facilities, the depuration pumps were the first or second largest consumers of electricity. Potential savings of between 3% and 22% were identified. In general terms the design and specification of the water circulation system has significant potential to reduce the electrical consumption and thus the emissions from depuration. Depuration pump flow rate was considered in excess of requirements and a VSD would match pump effort to the required flow rate.

- Installation of on-site renewables, notably solar photo voltaic (PV), and wind turbines. These would replace grid electricity with renewable electricity.

- LED lighting upgrades. Most sites were noted to have begun switching bulbs, but there was significant potential still to be realised. LED bulbs typically require less than half the electricity of fluorescent T8 tubes.

- Enhanced protections for shellfish waters – preventing combined sewerage overflow (CSO) releases, reductions of agricultural runoffs and higher standards for Waste Water Treatment Works (WWTW) discharges – might improve local water quality sufficiently to allow regrading as Class A waters which would not require depuration.

- Prioritise use of clean modes of transport in post-harvest supply chain.



Bottom-Grown Mussel LCA (Single Site Case Study)

Key points

- Emissions from this sector are relatively small, contributing 1.2% of Irish seafood total GHG emissions.
- Emissions per tonne are 823.9 kg CO_2 eq. per tonne of bottom grown mussels are considered low but significantly higher than rope grown mussels and oysters.
- Vessel fuel, for seed collection and site husbandry, is a key driver of GHG emissions.
- No physical structures or feed inputs are used in the culture phase thus contributing to a low emission profile for this sector.

Review

A review of the cradle to farm gate greenhouse emissions impacts was conducted for a bottom-grown mussel grower within the Castlemaine Harbour Co-Operative. The sample site produced 15 tonnes of bottom-grown mussels per annum (2017-2019). Bottom grown mussels are a key contributor to Ireland's aquaculture sector. In 2021, they accounted for 12% of volume and 4% of aquaculture sector value. As well as having high export volume and value, mussel harvesting provides employment for nearly 100 people across Ireland.

The mussel fishery includes both mussel seed (or 'spat') collection and the eventual transplant and on-growing aquaculture licenses in inshore bays. Seed collection takes place mainly on the Southeast coast of the Republic of Ireland using dredges. There is also a local fishery in Castlemaine Harbour. Gear is designed to skim the upper layer of sediment around aggregations of juvenile mussels with minimal impact to the underlying seabed.

The seed fishing mainly takes place in open waters with vessels ranging from 25-45m using two or more dredges measuring from 2-4m wide. Licensed vessels collect seed mussels within permitted harvest areas in Lough Swilly, (Cromane) Castlemaine, Youghal harbour, Waterford harbour, Wexford harbour, Lough Foyle, and Carlingford Lough South Shore. These are collected by towing a dredge behind a small boat.

Bottom mussels are sold in fresh (live) and prepared forms (fresh, frozen vacuum-packed mussel in sauce) and more advanced ready meals (half shell with toppings), and as frozen meats into the wholesale, retail and food service markets. Most Irish bottom-grown mussels are exported, mainly to The Netherlands and France.

Annual usage data on diesel (vessel, tractor, and teleporter), petrol (outboard engine generator), engine oil and anti-foulant paint (vessel) were provided by the sample site. However, data on figures for floats, refrigerant fugitive emissions and packaging were not available at the time and therefore these were left out of the impact assessment.

Upon completion of the bottom grown mussel case study it was recognised that the vessel diesel use is not representative of the wider bottom grown mussel activities as the case study has reduced vessel use. As a result, the average bottom grown mussels production and vessel fuel costs between 2017-2019 inclusive were used below (Table 13).

Table 13: Greenhouse Gas emissions from each main source in bottom-grown mussel culture.

Input	Impact (kg CO_2 eq.)	%
Diesel (vessel, tractor, teleporter)	775.13	94.2%
Petrol (outboard engine generator)	47.66	5.8%
Engine oil	0.19	0.0%
Antifoul paint (vessel)	0.21	0.03%
Total	**823.19**	**100%**

The above values equate to a GWP of 823.19 kg CO_2 eq./t of bottom-grown mussels at farm gate. In comparison the LCA study of rope-grown mussels was a GWP of 107.4 kg CO_2 eq./t of live-weight produced at farm gate. The GWP emission values associated with engine oil and anti-foulant paint were similar for both types of mussel culture.

The GWP value of bottom-grown mussels is nearly 7 times higher than the emission value of their rope-grown mussel equivalents. This higher value is thought to be largely influenced by the scale of rope-grown mussel production e.g., one rope-grown mussel site can produce 60 times the weight of a bottom-grown mussels site.

Potential Mitigations for the Bottom Mussel Sector

- Fuel use for vessels is the obvious target for emission reduction. Consideration should be given to the use of electric and/or hybrid propulsion systems given that this fleet occur within the inshore or near shore environment. Biofuel may offer potential to reduce emissions in the short term.
- Reduced effort for finding seed. Continued BIM seed mussel surveys and increased use of high-resolution side scan sonar technologies, coupling search efforts with improved seed settlement modelling capabilities (seed dispersal/hydrodynamic modelling).
- Seed: research alternative supply. Continued research into the rope growing of seed for transplanting to the seabed. This would help alleviate fluctuations in supply and would be a potential strategy for carbon reduction.
- General measures such as moving to clean technologies for powering refrigeration and transport.
- Champion the use of sequestered carbon and positive biodiversity impacts into carbon calculation methodologies.
- Prioritise use of clean modes of transport in post-harvest supply chain.

Section 7: *Nephrops* LCA

Key points

- Wild captured *Nephrops* caught by bottom trawl are a low carbon food when compared to terrestrial meat products.
- The GWP per tonne of *Nephrops* landed in Ireland is 4,206 kg CO_2 eq. This is a low figure when compared to some other studies of *Nephrops* fleets internationally.
- Fuel consumption by the vessel accounts for 96% of the GWP to quay side.

LCA Methodology

This LCA study focuses on the capture of *Nephrops*. The LCA methodology and system boundaries for these, and associated definitions are provided below for each process step. The product, direct emissions, and arising wastes are briefly outlined below and visualised in the report supplementary material.

Nephrops Overview

Norway lobster *(Nephrops norvegicus)*, also known as Dublin Bay Prawn and Langoustine, is a slim, orange-pink lobster which grows up to 25 cm (10 in) long. Adults inhabit muddy seabed sediments and emerge from their burrows at night to feed on worms and fish. Fishing for *Nephrops* is predominantly carried out by trawling (Figure 11).

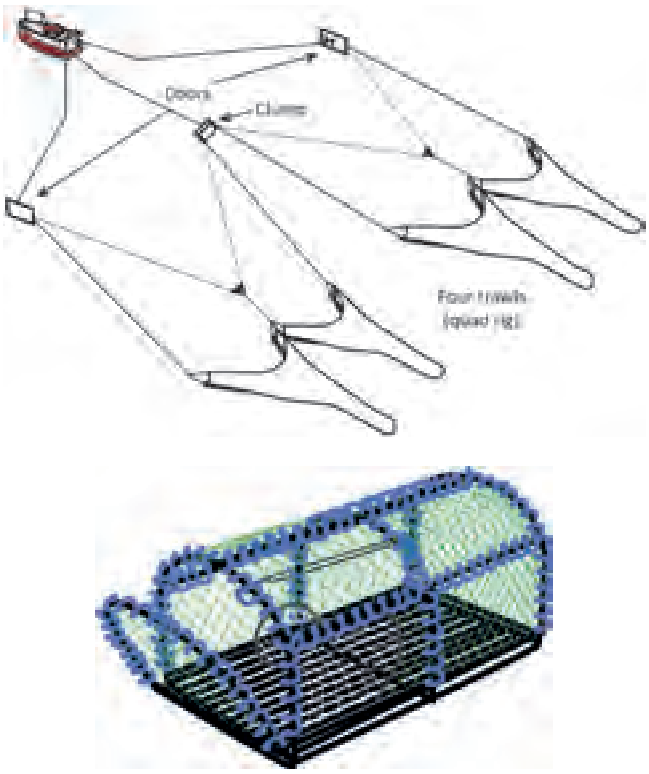


Figure 11 (right): The different gears used for *Nephrops* fishing in Europe L: Twin bottom otter trawl R: Creel fishing. Bottom trawl is the main gear used in the Irish *Nephrops* fisheries.

Unit Process 1: Capture Fishery

The majority of *Nephrops* landed by the Irish fleet are caught by bottom trawling, from seabed sites off the Irish coast. There are three main fishing grounds for *Nephrops*: Porcupine Bank on the Irish Coastal Shelf 200km west of Ireland, the Smalls off the south coast, and the Irish Sea. Vessels steam to the fishing grounds, then deploy their gear and tow. The catch is landed onto the vessel and then undergoes a number of primary processing steps on board, such as grading, packing and refrigeration. Within the LCA system boundaries of this study, the Fishing Unit Process includes the maintenance of the vessel. Direct vessel emissions such as bilge water and effluent were considered negligible based on knowledge of the process.

Unit Process 2 & 3: Landing and Transport

Once fishing is complete the catch is returned to shore and placed in vehicles to be transported to the processing facilities at the vessel's home port. In some instances, vessels based on the east coast may land catch at ports on the west coast for commercial reasons, before transporting them to their home port.

Sampling

Data was provided from two fishing Co-Operatives in Ireland: covering the period 2017 – 2019 In total, these vessels accounted for 10% of total freezer vessels in those Co-operatives. The percentage of the total Irish catch contained in the sample in each year is noted in Table 14.

Table 14: Percentage of the total Irish catch included in the sampled vessels in each year. The average covered by the sample was 5.5% of the total national catch.

Percentage of catch in our sample	2017	2018	2019	Average
Nephrops	3%	6%	7%	5.5%

Nephrops LCA Results and Analysis

Nephrops Results

The GHG emissions for different aspects of *Nephrops* fishing are given below (Table 15). These are expressed in terms of GWP (in kg CO_2 eq./tonne) of *Nephrops* landed.

Table 15: Global Warming Potential of landed Nephrops (kg CO_2 eq./tonne).

Process	Input	Average Imapct (GWP)	Total	%
Fishing	Fuel (Marine Diesel)	4,055.9	4,172.6	99.2%
	Engine Lubricants (15w40)	6.8		
	Fishing Gear (Nylon)	30.8		
	Fishing Gear (Wire - Stainless Steel)	13.8		
	Refrigerants (449a Gas)	0.0		
	Additives	3.3		
	Packaging	30.3		
	Antifouling Paint	1.4		
	Chemicals and Cleaners	6.2		
	Potable Water	0.3		
	General Waste from Consumables (peturned to port)	8.3		
	Waste Oil	15.2		
	Waste Fishing Gear – Nylon	0.1		
Landing	Ice (for Storage/Market)	0	6.6	0.2%
	Polythene Pallet Wrap	0.5		
	Pallets (Pine Wood) - 18kg per pallet	5.7		
	Washing storage areas	0		
	Cleaning Products for storage sreas	0		
	Electricity for storage/Market Areas	0.4		
Transportation	Catch return from Smalls by 40ft Truck	3.9	27.2	0.6%
	Catch return from Smalls by 20ft Truck	6.5		
	Catch return from Porcupine by 40ft Truck	6.3		
	Catch return from Porcupine by 20ft Truck	10.6		
Total			**4,206.51**	

Analysis

The LCA suggests a GWP of 4,206 kg CO_2 eq. equivalent per tonne of landed *Nephrops*. Key interpretations form this data include:

- The GWP impact value is similar to the wider analysis of Irish freezer vessels emissions analysis completed i.e., 5,172 kg CO_2 eq./ tonne landed.
- Fuel consumption by the vessel accounted for 96.4% of the GWP of the entire fishing process. This exceeds the approximately 87% reported by Ziegler and Valentinsson (2008).
- Transportation of *Nephrops* catch from other ports of landing to home port for processing and sale contributes an insignificant amount to the overall GWP of the process.
- The refrigerant consumption may be underestimated because the quality of the records maintained. This required that averages and estimates used in calculations.

The results for the Irish *Nephrops* fishery reported in this study are lower than those of other studies. Ziegler and Valentinsson (2008) estimated that the GWP for 1 kg of *Nephrops* landed to port and caught using trawling was 27.8 kg CO_2 eq. Also, for 1 kg caught using creels, they estimated a GWP of 7.18 kg CO_2 eq. However, all studies concur that, diesel combustion was the greatest contributor to GWP. Further, a 2016 working paper on the Scottish *Nephrops* fishery estimated that trawler caught *Nephrops* had a GWP of 10.34 kg CO_2 eq./kg and 7.81 kg CO_2 eq./kg for creel catch. It would appear that the Irish *Nephrops* fishery is operating with a relatively low carbon footprint. Further investigations on the different methods of fishing used would allow for deeper understanding and insight into this fishery and fishing activity.

Section 8:
RSW and Whitefish Case Studies

Key points
Refrigerated Seawater (RSW)

- This segment has the most modern vessels in the Irish fishing fleet.
- Shoaling fish like Atlantic mackerel and herring are relatively easy to target thus increasing the catch per unit effort and contributing to a lower GHG emission profile for this segment.
- 'Non seabed contact' gear reduces engine load and leads to lower GHG emissions for this segment.
- Pelagic fish have low GHG emissions per kg of fish landed and these low emissions are also reported in other pelagic fleets such as the Scottish RSW fleet.
- RSW (cooling) systems have been shown to be a highly efficient way of storing fish and this efficiency translates into lower carbon emissions.
- Higher resolution data for all phases of fishing effort would support the analytics required to further increase the efficiency of the RSW fleet.

RSW Case Study

Trawl nets are used for pelagic fishing. These are towed in mid water and target high density, shoaling fish such as Atlantic mackerel. Non seabed contact, high fish volume per trawl and efficient cooling systems are attributes that contribute to a lower emission profile for the pelagic fleet.

Anonymised RSW fleet segment data was provided to this study and this data was in aggregate form for 17 RSW vessels in the fleet. RSWs use cooling systems to store large volumes of fish such as Atlantic mackerel and blue whiting.

RSW systems have been shown to be a highly efficient way of storing fish and this efficiency translates into lower carbon emissions. Fishing tactics are summarised as follows: 15 vessels fished for horse mackerel, 14 fished for blue whiting, 8 fished for boarfish and 2 fished for albacore tuna.

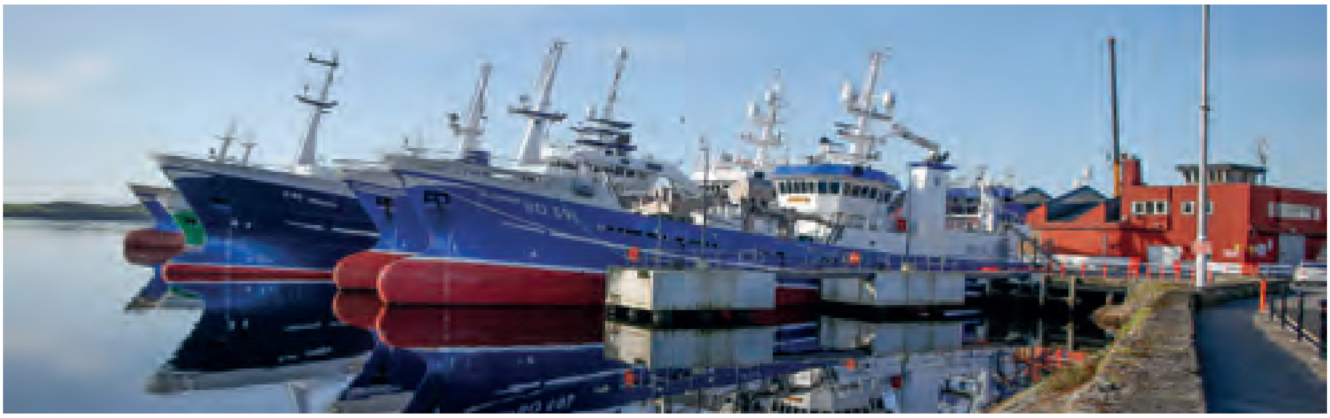


Table 16: The data from the NEPTUNUS project, as provided by the University of Galway showing species mix for the case study RSW fleet.

Catch			
Target species	**Number of Vessels**	**Unit**	**Avg Value (kg)**
Average Catch	17	kg	6,037,256
Atlantic Mackerel	17	kg	2,484,619
Horse Mackerel	15	kg	774,660
Blue Whiting	14	kg	1,402,132
Boarfish	8	kg	1,216,345
Albacore Tuna	2	kg	159,500

The species mix for the sample pelagic fleet is given in Table 16. However, this study found it difficult to accurately disaggregate these data for individual species due to data resolution. One of the key barriers to teasing out environmental and carbon footprints at species level is the seasonality of the fishing activity. The 'Species aggregated' dataset sampling a single year, did not provide enough 'data bandwidth' to estimate the carbon footprint for any one species. The findings show that the average emissions for a tonne of landed mixed pelagic fish such as Atlantic mackerel, horse mackerel, blue whiting and boarfish is in the region of 0.23 kg CO_2 eq./kg of fish landed. Some of the general points and key assumptions with respect to the overall GHG emission calculations for this segment is given next.

- Trawl doors and clump chains were assumed to have a life span of 10 years.
- Nets were assumed to have a 5-year life span for nylon and polypropylene components.
- Maintenance and repair rates for nets are as per indicated by respondents.
- Chain sections were assumed to last for 10 years with a 6% replacement rate per annum.
- Ammonia (R717) was the refrigerant used by the vessels. The production of ammonia was assumed to be produced using steam reforming rather than partial oxidation.

However, given the significance of Atlantic mackerel to Ireland's seafood economy, a high level analysis was carried out using the data available. The findings of the Atlantic mackerel case study LCA is provided opposite.

Table 17: Greenhouse gas emissions per tonne of Atlantic mackerel.

Process	Input	Impact (GWP kg CO_2 eq.)	Total
Fishing	Vessel Fuel (Marine Diesel)	113.78	114.13 kg CO_2 eq./ tonne Atlantic Mackerel
	Engine Lubricants (15W40)	0.06	
	Fishing Gear (Net maintenance - Nylon)	0.11	
	Antifouling Paint	0.18	

Average landings of Atlantic Mackerel accounted for 41.16% of the total catch (from average data) recorded by the sampled vessels. Table 17 records the result of calculations using data provided by the Neptunus project and the GHG emissions factors from EcoInvent. The total GWP for landing 1 tonne of Atlantic mackerel is calculated as 114 kg CO_2 eq., using the sum of the average catch for individual species (6,037t). The figure used to calculate the total GWP of the fuel consumption in the table above is 41.16% of the average figures provided as Atlantic mackerel accounted for 41.16% of the total landings recorded for the five individual species. Fuel consumption cannot be disaggregated for individual species, so the consumption has been allocated by weight. Fuel consumption accounts for 99.6% of the calculated total emissions in this case study.

The emissions per tonne of Atlantic mackerel landed were calculated at 114 kg CO_2 eq./ tonne and this figure is lower than the Irish RSW fleet segment(2017-2019 average) figure of 235 kg CO_2 eq./ tonne fish. These figures are consistent, albeit slightly lower, with other fishing fleets such as the Scottish RSW pelagic fleet as documented in the recent 'The environmental impacts of pelagic fish caught by Scottish vessels' report published in 2021. This report found that Scottish pelagic fleet had a carbon footprint of 0.452 kg CO_2 eq./tonne and that fuel consumption was the main source of emissions contributing 96% to the carbon emission total. This puts pelagic fishing as the lowest emission segment of all wild caught seafood categories and far less than land-based animal production. Metz *et al* .,(2022) calculated the Scottish 'over 40m pelagic' fleet emission value at 240 kg CO_2 eq./ tonne of fish landed.

Key points
Whitefish

- Fuel use is the main source of emissions – 97% for this case study.
- Fish landed by the case study vessel have a low emission profile 2.36 kg CO_2 eq./kg.
- Higher resolution data showing vessel speed, steaming and fishing duration, landings and fuel use, would be required to support decisions with respect to increasing efficiency.

Whitefish Case Study

In order to benchmark key segments of the seafood sector a case study LCA on Whitefish from cradle to farm gate was carried out. A Donegal Coop was selected for this study and provided data for an 18-year-old, 24.7m fishing vessel with a 441kW engine. Vessel specifications are below.

- Gear - 750 20mm combination steel and polypropylene (PP) rope.
- Nets - 1 x 120ft whitefish trawl and 1 x 150ft white/groundfish trawl.
- Warp: 2 x 400 fathoms x 24mm-diameter IWRC Bridon trawl wire (Total weight 2,900kg).
- Trawl doors: Larsen Fishing Gear (DK) 1 x LFG2019-006 HL-8 5.0m2-1100kg and 1 x LFG2019-007 HL-8 2.5m2-700kg.
- Polysteel Rope: 5 x 120m Coils.
- Refrigeration equipment: Buus 2.5T Ice Machine.

Consumption data was converted to a functional unit of one tonne of whitefish landed. The calculated GWP (in kg CO_2 eq./tonne of fish landed) by vessel resource (resources used by the vessel that contribute to emissions) is shown in table 19 (p74).

Table 18: Species by per centage of catch.

Species	2020 (tonnes)	% of Catch
Haddock	319,908	30%
Whiting	288,178	27%
Megs	201,427	19%
Monkfish	114,716	11%
Ling	42,409	4%
Hake	39,085	4%

Consumption data was converted to a functional unit of one tonne of whitefish landed. The calculated GWP (in kg CO_2 eq./tonne of fish landed) by vessel resource (resources used by the vessel that contribute to emissions) is shown in table 19.

Table 19: Percentage contribution to GHG emissions by resource.

	Impact (kg CO_2 eq./tonne Whitefish)	%
Diesel	2,308.9	97.9%
Engine Oil	12.4	0.5%
Cleaning Fluid	3.7	0.2%
Antifoul Paint	0.3	0.0%
Gas (R449a)	32.3	1.4%
Ice	0.22	0.0%
Waste	1.34	0.1%
Total	**2,359**	**100%**

The above table clearly shows that 97.9 % of catch emissions to quay side are attributed to diesel use. The GWP for one tonne of white fish landed by this vessel is 2.36 tCO_2 eq. This is slightly higher that the figures calculated for the Irish 'Prawns and Whitefish 24-40m' segment value of 2.09 tCO_2 eq./ tonne fish landed. This may be the result of fishing tactics and fishing location. However, higher resolution data showing vessel speed, steaming and fishing duration and fuel use would be required to make a definitive conclusion on this. The carbon emissions for fish caught by this vessel are at the lower end of average seafood emissions and well below those for terrestrial animal protein production. Data for wire and nets were not used for the above carbon calculation. However, these are not considered to be a significant contributor to the overall GWP.

Based on the above analysis of data available, it is clear the large majority of the GWP is attributed to marine diesel consumption of the vessel. Mitigation of this marine diesel related GHG emissions is covered within the vessel review section of this report.

Section 9: Transport

Key points
Transport and processing

- The majority of Irish seafood is exported. Mode of transport is important in terms of carbon footprint calculations. Air transport significantly increases carbon footprint when compared to sea and road transport.
- Seafood that is transported live or fish that is cooked and transported by air will have a higher emission profile than fresh or frozen product transport by sea or road.
- The degree of food processing is proportional to the level of GHG emissions. In general seafood is not subject to high levels of processing and is rarely considered an ultra-processed food. This means that the carbon footprint associated with the fish processing is generally less than other food types.
- For finfish, gutting and refrigeration contributes to GHG emissions but to a much smaller scale than sea fishing (fleet) or feeding fish (aquaculture).

Transport to Main Markets

The Irish seafood sector exports the majority of its produce and sends seafood to various destinations around the world. However, there are established markets for many of these products, and these have been used to model the impacts of the transport from producer to first customer. The 2021 exports to key markets, by value and species is outlined in BIM *'Business of Seafood'* report (2021) (Table 20 and 21).

Table 20: 2021 exports to key markets by value and species. Reproduced from BIM' Business of Seafood'(2021).

Rank	Partner Country	Value 2021	Value Growth	Main Export Species	Share Of Partner Total
1	France	€164m	+34%	Salmon Oysters Crab	36% 15% 13%
2	United Kingdom	€79m	-13%	Fish Meal Salmon Fish Fats And Oils	23% 18% 8%
3	Spain	€65m	+20%	Dublin Bay Prawn Monkfish Crab	18% 16% 13%
4	Italy	€58m	+32%	Dublin Bay Prawn Shrimps And Prawns Mussels	71% 14% 4%
5	Nigeria	€38m	-23%	Blue Whiting Mackerel Horse Mackerel	63% 28% 9%
6	China	€28m	+126%	Mackerel Oysters Crab	50% 13% 13%
7	Germany	€28m	+10%	Salmon Mackerel Herring	67% 19% 6%
8	Poland	€26m	-41%	Salmon Mackerel Herring	61% 31% 4%
9	Egypt	€20m	+4%	Mackerel Horse Mackerel	62% 38%
10	Japan	€18m	+61%	Mackerel Horse Mackerel Herring	55% 26% 10%

Table 21: Value of exports to global regions. Source: BIM Business of Seafood report (2021).

Main Markets	Value €M 2020	Value €M 2021	Volume Tonnes 2020	Volume Tonnes 2021
European Union	338	397	95,200	107,900
Asia	54	80	23,500	36,800
United Kingdom	91	79	52,500	45,600
Africa	75	65	76,500	88,500
Rest Of The World	22	27	28,000	28,500
Middle East	25	26	27,400	25,400
Grand Total	**605**	**674**	**303,100**	**332,700**

Methodology

The analysis was based on the functional unit of 1 tonne of product. No allowance was made for losses, e.g., mussels were assumed to be transported whole from the origin to the destination. BIM provided information on the most common destinations for the species under study, which formed the basis of the route mapping analysis. To support this analysis, the largest supplier in the sample was considered the origination point, while the capital of each country named was considered the end destination. Distances of travel for each transport mode were taken from online calculators as indicated below:

- Road - Google Maps
- Sea - ShipTraffic.net
- The sea route chosen was from the Port of Dublin, with the choice of destination based on the specific route information supplied by BIM, the location of the main container port in the country, and the proximity to the destination
- Air - AirMilesCalculator.com. The nearest international airport to the destination.

A key assumption made when modelling this data was that there was direct travel between nodes, i.e., the product travels direct from landing to the next point in the chain and then onwards to the destination. In practice the route is usually less direct and frozen product carried by a freight forwarder may travel through a varying number of nodes en route to the destination. Once the modes and distances had been calculated, the coefficients for each transportation mode from Ecoinvent were applied. The output is then a figure for the amount of CO_2 eq. emitted for one tonne of the product for the entire journey from producer to final distribution hub, e.g., retailer in the destination city.

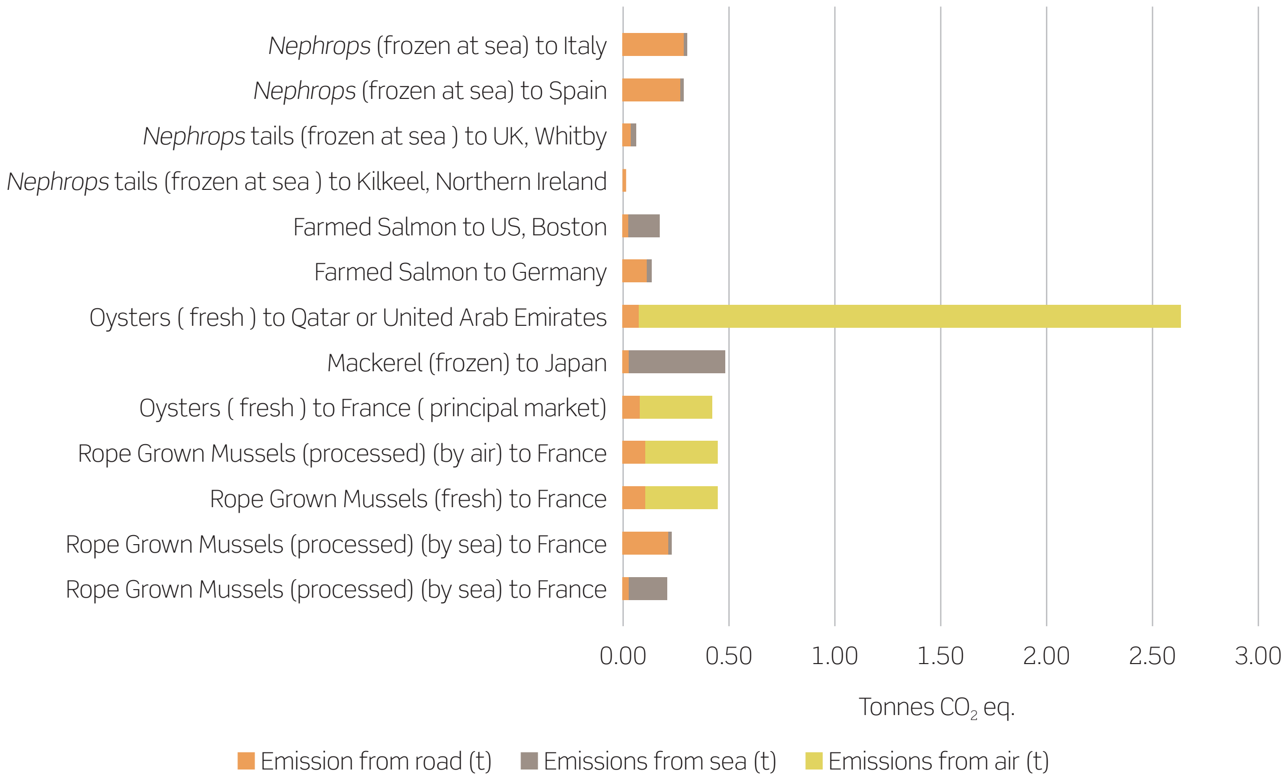


Figure 12: Tonnes CO_2 eq. per tonne of seafood species transported. The size of and contribution to the overall impact of selected species and travel to their main market. Oysters sent to the Middle and Far East, by air freight are by far the largest emitters of GHGs per tonne of product, with the size of the bar indicating the amount of CO 230_2 eq. emitted for the typical journey.

Figure 10 shows the size of and contribution to the overall impact of selected species and their travel to their main market. Oysters sent to the Middle and Far East, via air freight are by far the largest emitters of GHGs per tonne of product, with the size of the bar indicating the amount of CO_2 eq. emitted for the typical journey. The transport of these products generally emits less than 500 kg CO_2 eq./t of product going to their main market.

The exception to this are fresh oysters going by air to the Middle and Far East, with over 2,500 kg and almost 4,500 kg per tonne, respectively. It is clear from this graph that the transport of fresh product by air has a significantly greater per unit impact than that of processed or frozen product. Comparing the difference between frozen Atlantic mackerel to Japan (by sea) and fresh oysters (by air) to the Far East demonstrates the massive difference that air travel makes for carbon emissions.

Figure 13 highlights some of the differences the transport mode makes in lower impact product markets.

Farmed salmon to Boston, USA has only a slightly larger footprint than the same salmon sent to Berlin in Germany. This is due to the much lower emissions from sea transport compared to road. However, it is noted that Boston is unlikely to be the final destination, therefore, and additional road haulage emissions would need to be added. Note also that fresh oysters to France have a lower total transport emission than rope grown mussels making the same journey. This is due to the location of the farm in Ireland. The modelling used the location of the largest producer in the study as the source and Dublin airport as the departure point, so the initial road transport distance accounts for the difference.

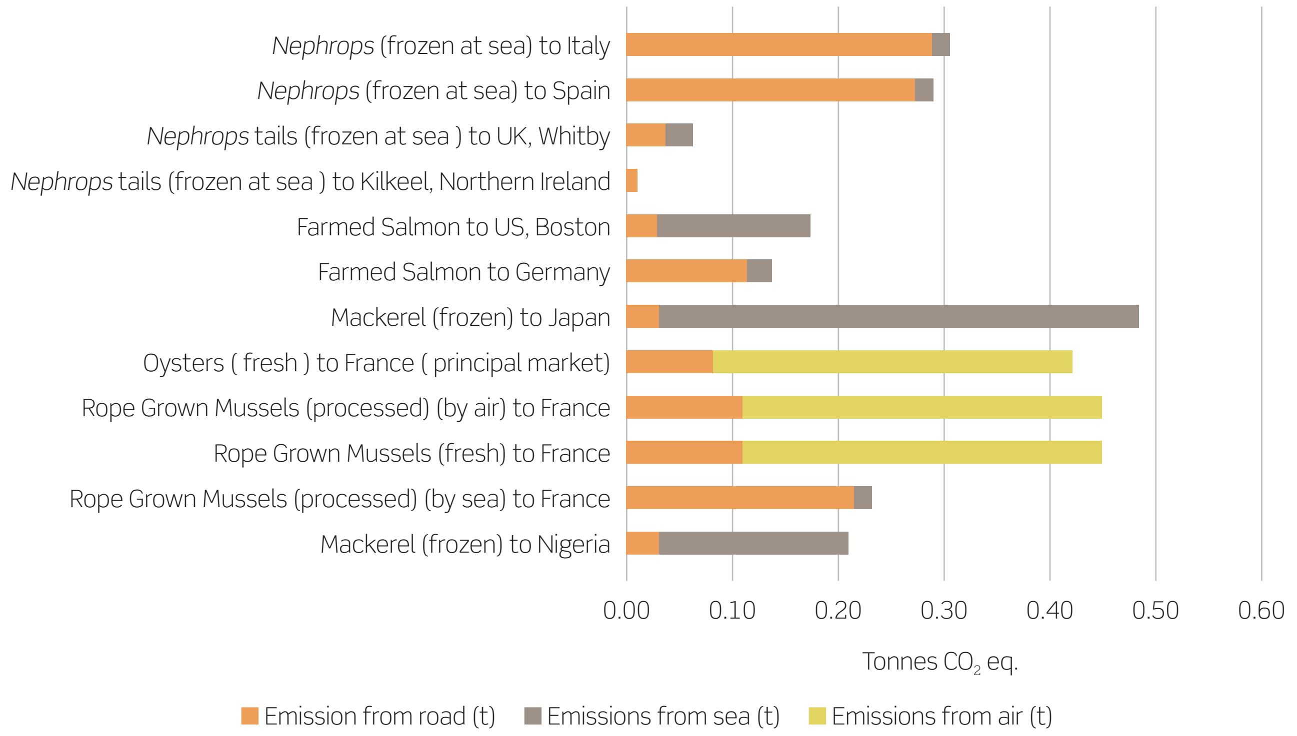


Figure 13: Overall impact (oysters to Middle and Far East excluded).

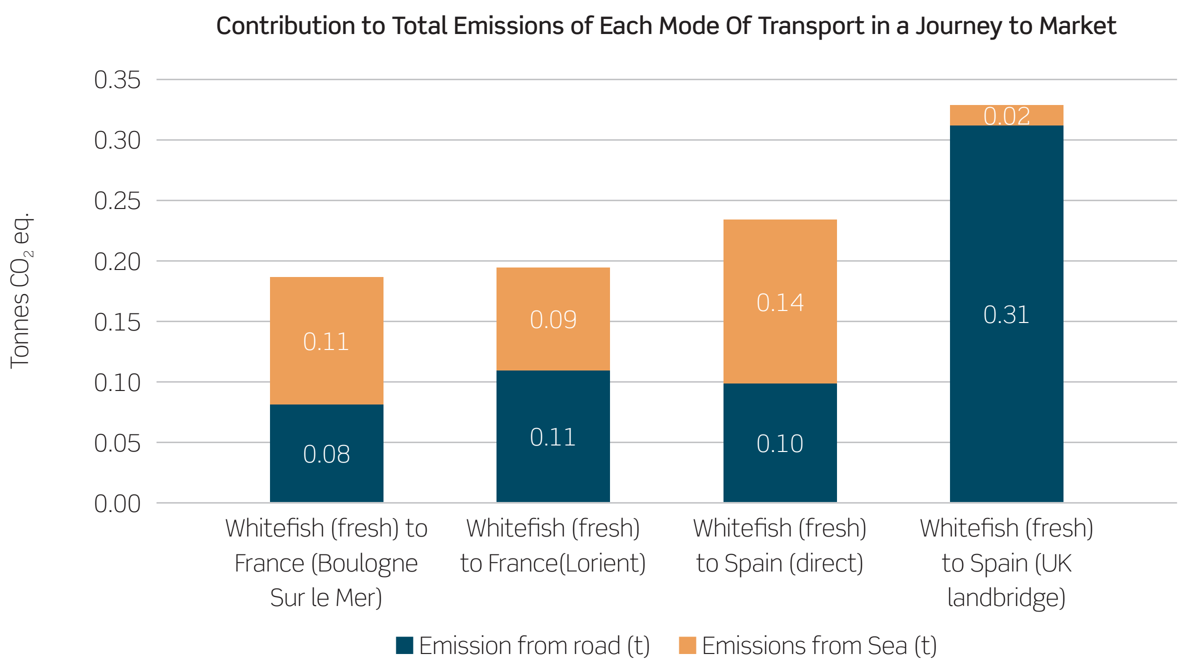


Figure 14: Tonnes CO_2 eq. from road and sea travel for products going to France and Spain.

The transport of product into Europe involves a range of potential routings, as shown in Figure 15. The two routes for whitefish into France (final destination assumed as Paris) have a similar total impact, at just under 200kg/t, but the proportion of the road and sea emissions is reversed because L'Orient is a shorter sea journey, but further from Paris. There are two typical options to send whitefish to Spain (assumed destination Madrid) – by sea or by road. The seabridge has options to land at ports along the Spanish Atlantic Coast, or even in France, and the route modelled in this instance is to Bilbao, which is the closest major port to Madrid. This option is likely to result in 40% lower emissions than the alternative route by road through the UK and France.

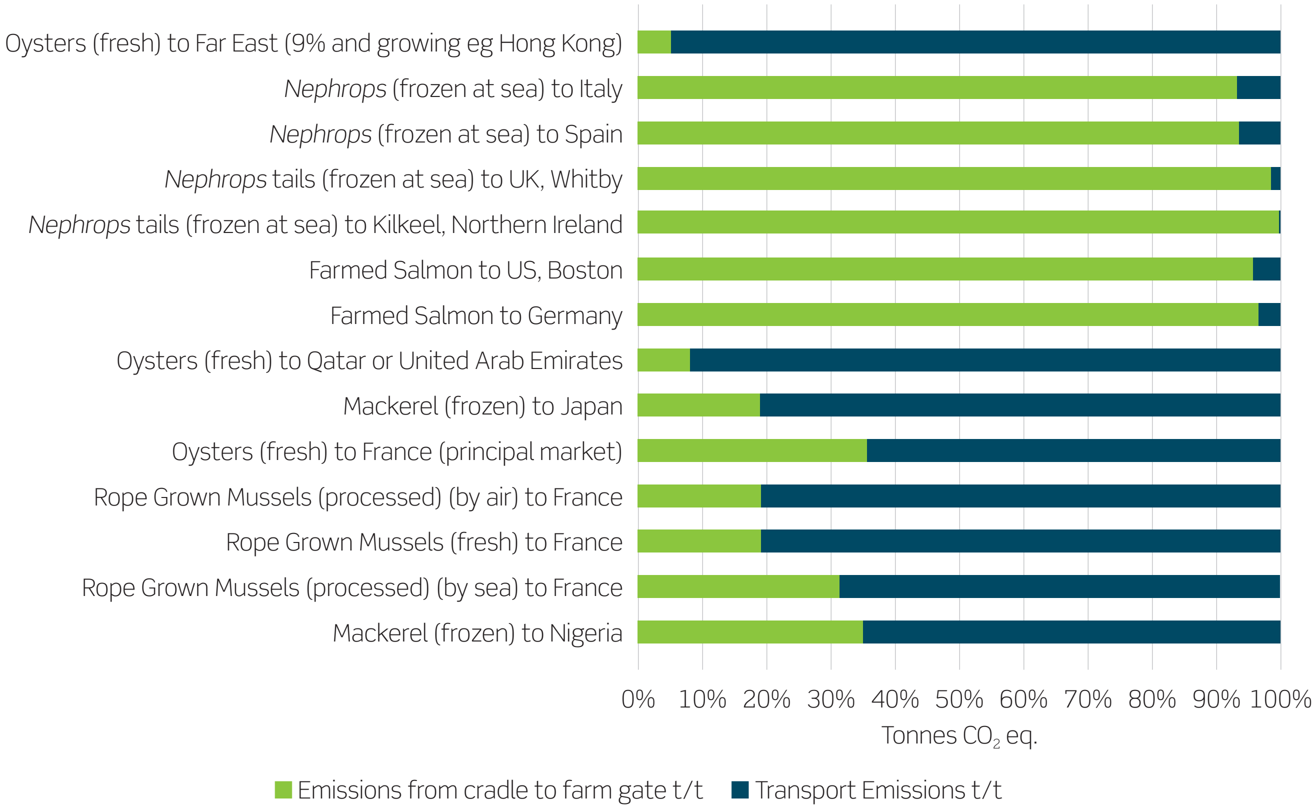


Figure 15: Tonnes CO_2 eq.as a % comparing the 'cradle to farm gate' emissions to the emissions of transport to market.

Figure 16 shows the factoring in of both 'cradle to farm gate' and transport emissions. It can be seen the largest emissions per tonne seafood is fresh oysters transported to the Far East by air freight whereas the smallest emissions per tonne seafood is Atlantic mackerel (frozen) transported to Nigeria by sea.

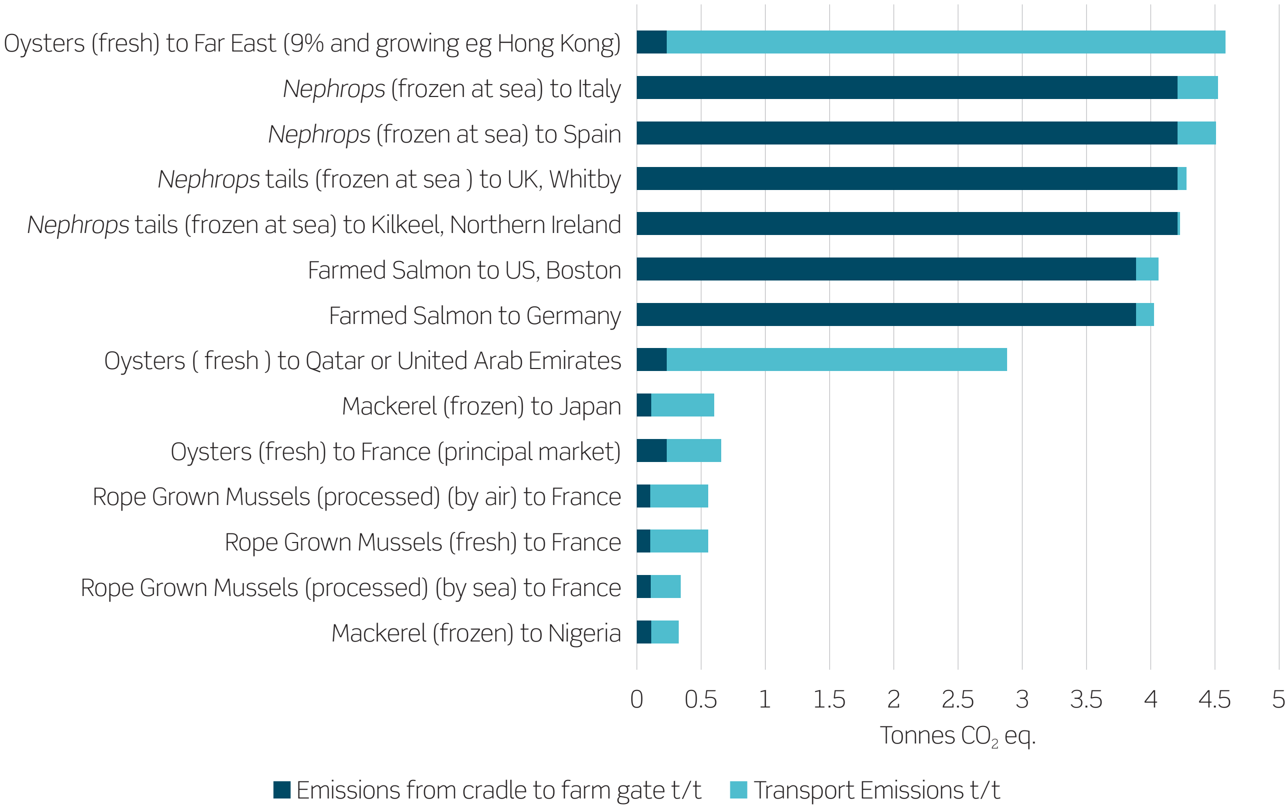


Figure 16: Tonnes CO_2 eq./tonne seafood from 'cradle to farm gate' compared to the emissions of transport to market.

Section 10:
Secondary Processing and Food Waste

Key points
Food Waste

- Food wastage accounts for circa 6% of total global GHG emissions. This makes food wastage a key area to target in terms of Climate Action (for all food types including seafood).
- Food waste equates to resource wastage (raw material, energy, water, fuel), therefore reducing food waste will reduce Carbon emissions.
- Circa 66% of food waste is the result of poor storage and handling techniques, and spoilage in transport and processing.
- Circa 33% of food waste comes from food thrown away by retailers and consumers.

Quantifying the GHG emissions of the secondary processing and associated seafood wastes was not part of the scope of this project. An overview of reported emission impacts at these stages of the seafood lifecycle is provided below, based on the literature review conducted during this project.

Food waste is a global problem, with approximately one third of all food produced ending as waste, equivalent to 1.3 billion tonnes per year. The EU fares slightly better but still estimates that around 20% of all food produced is wasted.

The figure below illustrates the study by Poore and Nemecek (2018) in their large meta-analysis of global food systems, found that supply chains account for 18% of food emissions. Food processing, transport, packaging and retail all require energy and resource inputs (Poore and Nemecek, 2018).

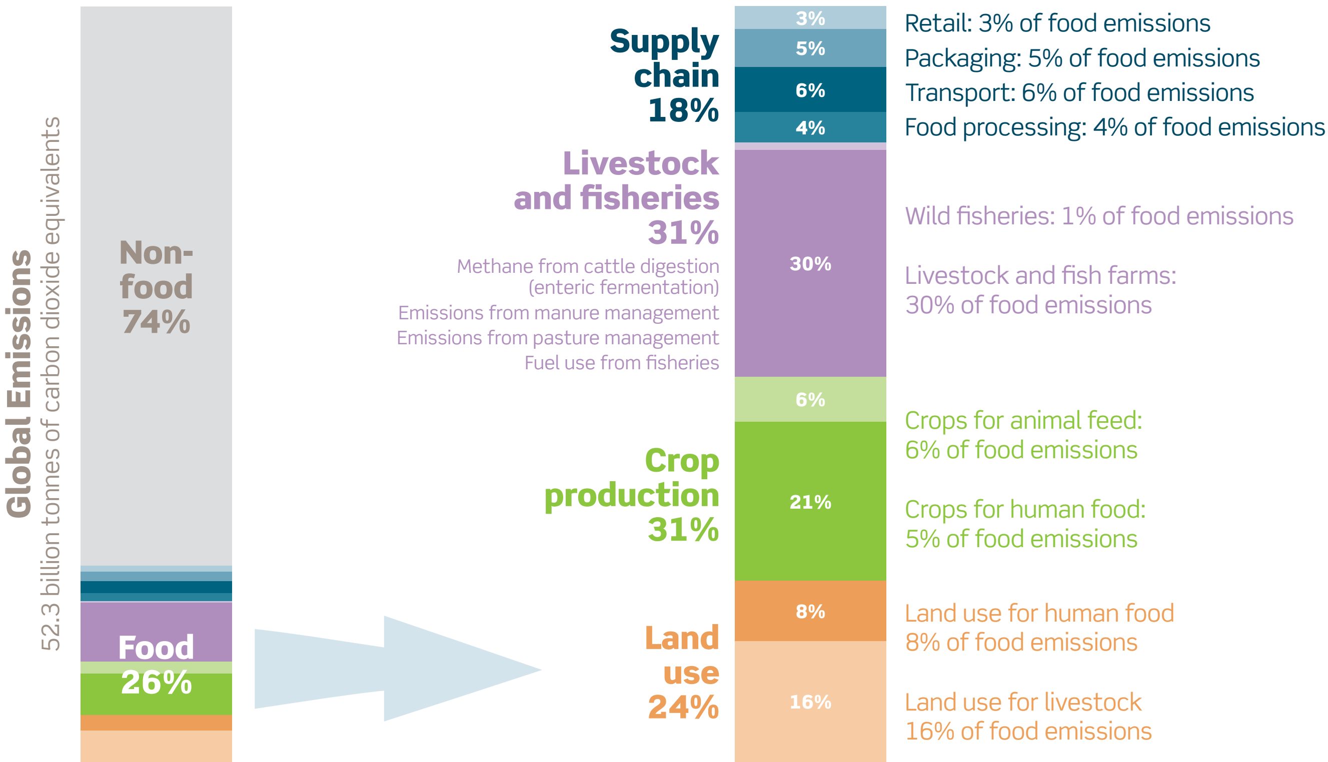


Figure 17: Global GHG Emissions from Food Production (Poore and Nemecek 2018).

Each stage of the supply chain - processing, transport, packaging and retail - accounts for a similar amount. Each was around 5% of food emissions. Poore and Nemecek's (2018) study found that almost one-quarter of food emissions come from food that is lost or wasted by consumers. Of this, it is estimated that approximately, two-thirds of emissions comes from losses in the supply chain resulting from poor storage and handling (i.e., refrigeration and spoilage in transport). The remainder of food loss and waste emissions comes from retailers and consumers (www.ourworldindata.org). Based on this it is estimated that food waste and loss accounts for 6% of total global GHG emissions. This value may be an underestimation as in their work, Poore and Nemecek (2018), they do not include food losses at the farm or production level.

The EPA estimate that Ireland wastes approximately one million tonnes of food each year and that "current estimates of food waste in the processing and manufacturing sector is around 500,000 tonnes".

Table 22: Summary of food waste in Ireland 2019 (EPA).

Sector	Tonnes of food waste	Reporting Status
Primary Production	70,415	Fair
Process and Manufacturing	497,448	Progressing
Retail and Distribution	111,297	Fair
Restaurants and Food Services	236,530	Fair
Households	254,745	Good

Good Fair Progressing

Source: EPA report 'How much food do we waste in Ireland, 2021'

The Waste Action Plan for a Circular Economy is Ireland's roadmap for waste planning and management. The Plan describes the Irish approach to managing food waste, and links with a number of other national plans and policies including the Climate Action Plan. It advocates a target for 50% reduction in food waste, which is in-line with the EU's target. It also matches the level of ambition being shown across the EU through the European Green Deal, which includes the new Farm to Fork Strategy.

Food waste reporting is due to become a mandatory part of Ireland's National Waste Statistics obligations, with reporting to begin in June 2022. The Food Waste Charter is a public commitment by companies and organisations in Ireland to fundamentally change how they think and respond to food waste. The signatories are pledging to take positive actions - through measuring; reducing; and reporting their food waste.

Beyond the resources that are lost, there is also the contribution to climate change that this waste creates. In Ireland, the annual carbon footprint of this food waste is estimated at 3.6 million tonnes CO_2 eq. That is the same as the average annual electricity consumption for 700,468 homes and would require the planting of 4.2 million acres of forest per year to offset.

Comparatively food waste generates approximately 8% to 10% of global greenhouse gas emissions, and if food waste were a country, it would be the third highest emitter of greenhouse gases in the world. Therefore, reducing food waste is an effective climate action for both producers and consumers.

Many of Ireland's seafood processing sites are members of the Bord Bia Origin Green Programme which stipulates annual reporting of sustainability performance and drives continual improvement through SMART targets across raw material supply, energy, water, waste as well as social sustainability.

The impact from seafood waste GHG emissions is dependent on weight and waste management route. Waste can be generated at various stages in the food system, from fish mortalities, quality control food waste, secondary processing off-cuts, processing waste, retail waste and consumer plate waste.

A paper titled 'Valorization of Marine Waste: Use of Industrial By-Products and Beach Wrack Towards the Production of High Added-Value Products' (Rudovica *et al.*, 2021) provides a comprehensive overview of various types of fish and shellfish waste and the processing options to support reduction of food waste and associated emissions, including valorisation, animal feed and anaerobic digestion.

Case studies are noted covering farmed salmon, mussels, and prawns among other species across European countries (e.g., Spain, Norway, Scotland). Key points from this paper are summarized below including potential food waste mitigation opportunities.

- The FAO, estimated that in 2018, about 88% of total fish production was used for human consumption, with the remaining 12% used for non-food purposes (FAO, 2020).
- By-products from fish processing, in some cases were estimated to be up to 75% of the original raw material (*Rustad et al.*, 2011). The study found that these by-products currently have low commercial value.

- In Norway, most by-products from fish and shellfish are used in some way (*Johansen et al.*, 2019). In 2020, about 861,000 tonnes (85%) of by-product material was utilised (*Myhre et al.*, 2021).
- Most by-products from pelagic fishing and aquaculture can be used as silage, fishmeal, fish oil and fish protein concentrate. According to the FAO there is a growing trend of using by-products as materials to make fishmeal and fish oils. (FAO, 2020).
- Other uses of by-products include the use of shells from aquaculture. For example, in Galicia (Spain), Mediterranean mussel shells are used in agriculture for PH regulation in soil (*Morris et al.*, 2019).
- Sludge from land-based aquaculture and smolt production can be used for biogas production, with the remaining digestate offering potential as a soil enhancer.

Section 11:
Key points for industry

Key points
The key findings of this study are summarised below

The Irish seafood sector will be highly impacted by climate change

The seafood sector will be seriously impacted by global warming and climate change in numerous ways. The size, distribution, spawning and mortality of fish stocks will be altered by warmer waters, ocean acidification, changes in ocean currents, and a higher frequency of severe storm events. For example, research suggests that Atlantic mackerel and North Sea cod now have a more northerly distribution due to related changes in the marine environment. The changing marine environment will impact Irish aquaculture and pose a variety of challenges such as altered shell development, changes to shellfish seed recruitment, as well as altered disease, parasite, and invasive species profiles. Research suggests that warmer Irish waters will increase physiological stress on farmed salmon and may lead to sub-optimal growth.

Decarbonising is necessary for safeguarding ecosystem sustainability and biodiversity

Human activities and their associated GHG emissions are the primary cause of global warming, climate change and ocean acidification. These changes seriously threaten global food systems and will reduce ecosystem sustainability and biodiversity. To combat this, all sectors of society are seeking to decarbonise. This combined effort to deal with global warming, is referred to as climate action. The Irish government has already published and is developing new national climate action plans to decarbonise the Irish economy and achieve Net Zero carbon emissions by 2050.

The carbon emission baseline as documented in this report will act as a starting point for future climate action plans in decarbonising the Irish seafood sector.

Consumers are highly aware of carbon emissions and the link to sustainability

Research by Bord Bia indicates that consumers see a low carbon footprint as a positive attribute that influences their food purchasing decisions. This is reflected in the purchasing strategies of buyers at mainstream retail outlets, as they focus their attention on Scope 3 of the GHG protocols, to reduce emissions in their supply chains. Fishing and aquaculture operations will increasingly be required to demonstrate their carbon credentials to these buyers, and this can only be achieved by developing a carbon baseline and by implementing decarbonising plans, backed up by supporting evidence (data) that climate action targets are being achieved. In the future there will be an increased move towards eco and carbon labelling of all food products. Statements such as 'low carbon' are already appearing on product packaging and so too are carbon footprint estimates, often expressed in terms of carbon equivalent emissions per kilo of food, e.g., 0.107 kg CO_2 eq./kg of mussels.

The seafood sector is a relatively low GHG emitting sector

This report confirms that GHG emissions from the Irish seafood sector are relatively low when compared to other food producing sectors such as farming. Food production globally accounts for approximately 30% of total carbon emissions from human activities. However, the global seafood sector only accounts for a small portion of this overall figure (circa 4%).

In Ireland, the agriculture sector contributes 27% of all Irish GHG emissions. However, the Irish seafood sector only generates a fraction (less than 2%) of the Irish farming GHG emissions figure.

Irish seafood is a relatively low carbon food

This report confirms that the GHG emissions from Irish seafood are relatively low when compared to other food types such as poultry, beef or lamb. 0.107 kg CO_2 eq./kg of mussels compared to 11.75 kg CO_2 eq./kg of cattle (Teagasc, 2021). Irish seafood is generally found to be a 'relatively low carbon food source'. These findings could potentially be exploited in the marketplace through positive messaging to environmentally conscious consumers and by labelling seafood products to highlight these low carbon credentials.

The seafood sector is diverse, and the carbon footprint varies within the sector

The seafood sector is unique and operates differently to other sectors of the economy. This sector is diverse with boats fishing and landing a variety of species - from Atlantic mackerel to lobster - from various locations, using different techniques. In essence, the seafood sector is made up of numerous sub-sectors and each of these has a unique GHG emission profile.

In general terms, fish that shoal in high density, such as Atlantic mackerel, which are caught by the modern Irish pelagic fleet, demonstrate a very low carbon footprint (0.23 kg CO_2 eq./kg). Farmed shellfish such as mussels and oysters also have very low carbon emissions, and some studies suggest that shellfish farms can be considered to have 'negative emissions' i.e., they sequester more carbon than they release.

Fish landed using bottom trawled gear have been found to have relatively low carbon footprints when compared to non-seafood food types. However, the emissions for these sub sectors (*Nephrops* and some whitefish) are higher than those of the pelagic sector and shellfish growing sectors. The emission profile for the *Nephrops* and whitefish sectors are comparable to those of chicken produced in the EU, on a per kilogram of harvest basis.

Farmed Irish organic salmon (3.9 kg CO_2 eq./kg) is also a relatively low carbon food and has a similar carbon footprint to chicken and far less than that of beef or lamb at 11.75 kg CO_2 eq./kg and 10.8 kg CO_2 eq./kg, respectively (Teagasc, 2021, 2022).

Seafood supply chain has emission hotspots

This report clearly demonstrates some seafood supply chain carbon emission 'hotspots'. The Irish seafood sector relies on diesel for its fishing fleet (accounting for circa 90% of all fleet GHG emissions) and imported aquaculture feed for the salmon farming sector (accounting for 60% of emissions for salmon farming). These aspects of the Irish seafood sector are obvious and clear key target areas for the future reduction of the sector's carbon footprint.

The Irish seafood sector is highly export focused. Transport mode and the imminent electrification of the road haulage fleet will have a significant effect on reducing post-harvest supply chain emissions for seafood. The majority of Irish seafood is distributed either by road or sea. However, it has been shown that seafood products that are distributed by air have a significantly elevated carbon emission profile, and this too is an area to be tackled in the future.

Urgent need for a seafood sector decarbonising plan

The report highlights the urgent need for a detailed seafood sector decarbonising (Climate Action) plan. As a starting point, the seafood sector should be seeking emissions reduction in the order of 7% per annum from now until 2030. There is also a strong need for business level climate action advisory services, so that seafood businesses are clear in terms of what they should be doing from an emissions perspective.

Data and knowledge management – monitoring and reporting of emissions are essential to achieving climate targets

Data management is a cornerstone of monitoring and improving the carbon performance of the seafood sector. The ideal scenario is where detailed fuel, energy, landings, and production data are stored and managed in a standardised fashion across the seafood sector. This approach would cater for an evaluation of the sector's carbon performance trends over time. Ultimately, climate targets need to be set and achieved. Proof of successful target attainment can only be demonstrated using solid data.

The same principle applies to knowledge management, whereby insight in relation to research, as well as industry and consumer trends internationally, will need to be managed in a way that the Irish seafood sector can access in a user-friendly fashion.

Direct and indirect emissions need to be accounted for in decarbonising plans

The GHG protocols discussed in this report show than emissions fall into direct (Scope 1) as well as indirect categories (Scope 2&3). Direct emissions relate to items such as fuel use and feed inputs. Indirect emissions are those generated by suppliers in upstream and downstream supply chains. For example, transport of seafood is considered to be Scope 3. Emissions relating to Scopes 1, 2 and 3 are all relevant to driving down the carbon footprint of seafood products and businesses. To achieve reduced emissions in seafood, there is a need for a partnership mindset across the entire seafood supply chain whereby different actors in the seafood sector work together to reduce the carbon footprint of seafood.

The drive to decarbonise will increase

As the climate crisis deepens, the pressure to reduce carbon in the food supply chain will continue to grow. The main reasons for this are as follows:

- Environmental changes and ecosystem disruption as a result of climate change and resultant knock-on effects and general supply chain issues.
- Government Policy and international agreements such as the UN Paris Agreement 2015 designed to combat the climate crisis (Climate Action).
- Fuel costs and risks associated with fuel price volatility.
- Retailers wish to reduce Scope 3 emissions (Seafood suppliers are 'Scope 3' for retail buyers).
- Consumer demand and their wish to purchase low carbon food and a desire to support environmental sustainability and biodiversity.

This means that, by acting now, the seafood sector will be future proofed and more resilient, especially with respect to long term sustainability as well as operational resilience, as viability is increasingly impacted by rising fuel end energy costs as well as emerging market trends such as the drive towards low carbon footprints in food products.

Climate action – short, medium and long term

In the short and medium term, decreases in the carbon footprint of the seafood sector will be achieved by increasing efficiencies relating to the growing and capture of fish and shellfish. These efficiencies and carbon mitigation measures are already visible in the seafood sector today, and include, for example, lighter fishing gear with less drag, use of shore power when vessels are at quay side, use of fuel metres, and a general move towards circularity in terms of business models encompassing the mantra of 'reduce, reuse and recycle'. In the short term, 'plug and play' fuels such as bio-diesel and HVO look likely to form part of the transition away from fossil fuel given their lower emissions profiles.

In the long term, Irish fishing fleets will move away from using fossil fuels towards low or no carbon alternatives. There will be a transition to fuels such as hydrogen, ammonia, and biofuels. Infrastructure will remain a significant barrier to achieving these aspirations for the time being. It is anticipated that hybrid electric engines will increasingly be seen in the offshore fishing fleet, and the inshore fleet is also seen as suitable for the use of electric engines. However, the barriers of cost and infrastructure will apply here also.

In aquaculture, given the general remote location of most operations, there is a unique opportunity to increase the use of renewable energy, particularly from solar and wind. Aquaculture support vessels will also increasingly be powered by hybrid electric and pure electric engines. Biodiesel and HVO will be part of the fuel mix too. For finfish aquaculture, life cycle assessments show that feed is the biggest source of carbon emissions and continued performance improvements are expected in this area. However, the feasibility of building a feed production plant in Ireland remains in question. Again, resource circularity as a concept has very much been adopted by the Irish aquaculture sector, and this will continue into the foreseeable future.

The future fishing and aquaculture sectors will be Net Zero emissions by 2050

The seafood sector like other sectors in the economy is moving towards Net Zero emissions by 2050. To support this transition, further research and investigation will need to be conducted in order to understand the carbon footprint of the Irish seafood sector.

The costs and feasibility of adopting different fuels will need to be assessed and a continuous watching brief on technologies used in other sectors such as farming and transport, as well as innovations in other countries, will be of increasing importance. All this highlights the key importance of knowledge management for the benefit of the seafood sector.

All steps in the seafood supply chain need to play a part in reducing emissions. In addition to 'at sea' operations, our research suggests that transport and food waste reduction are the post-harvest/production supply chain steps where significant gains could be achieved. Irish seafood is a 'low carbon food', so continued positive messaging, education and labelling will be required to convey this message and help boost the competitive advantage of Irish seafood in the marketplace. Finally, moving towards Net Zero emissions by 2050 will present both a challenge and an opportunity for the Irish seafood sector.

Section 12:
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