Ireland's Seafood Development Agency

# Carbon Footprint report of the Irish Seafood Sector

## Supplementary Materials

Bord Iascaigh Mhara

2023

Rialtas na hÉireann
Government of Ireland

Cómhaoinithe ag an Aontas Eorpach
Co-funded by the European Union

# Supplementary Materials - Contents



# Acronyms used

| | |
|---|---|
| **ASC** | Aquaculture Stewardship Council |
| **B2B** | Business to Business |
| **B2C** | Business to Consumer |
| **CFP** | Common Fisheries Policy |
| **$CO_2e$** | Carbon Dioxide Equivalent |
| **DCF** | Data Collection Framework |
| **EC** | European Commission |
| **EF** | Emission Factor |
| **EMFAF** | European Maritime Fisheries & Aquaculture Fund |
| **ESI** | European Structural and Investment (funds) |
| **EU** | European Union |
| **FEAP** | Fishing Effort Adjustment Plan |
| **GHG** | Greenhouse Gas |
| **GT** | Gross Tonnage |
| **GWP** | Global Warming Potential |
| **ISO** | International Organization for Standardization |
| **kW** | kilowatt |
| **LCA** | Life Cycle Analysis |
| **MSC** | Marine Stewardship Council |
| **OP** | Operational Programme |
| **PAS** | Publicly Available Specification |
| **t** | Metric Tonne |
| **TOR** | Terms of Reference |
| **VCU** | Vessel Capacity Unit |
| **FUI** | Fuel Use Intensity |

# Methodology - Aquaculture

## Life Cycle Assessment Approach

### Overview

This LCA was performed in accordance with the requirements of BS EN ISO 14040:2006, BS EN ISO 14044:2006, PAS 2050, PAS 2050-2:2012 which provides the supplementary requirements for the application of PAS 2050:2011 to seafood and other aquatic food products.

The LCA process requires four stages: goal and scope definition, inventory analysis, impact assessment, and finally interpretation of the results which takes place concurrently with the previous three strategies (ISO 14040).

The results obtained from this LCA shall be valid for a maximum period of two years, unless there is a change in the life cycle of the systems under consideration, in which case the validity ceases. All data supporting this LCA shall be documented and maintained in a format suitable for analysis and verification; records shall be held for a minimum of three years.

### Life Cycle Impact Assessment

This report focusses on the GWP environmental impact category. GWP is defined as the cumulative radiative forcing, both direct and indirect effects, over a specified time horizon resulting from the emission of a unit mass of gas related to some reference gas (Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories).

Each input identified within the individual system boundaries for each species was identified, thereby allowing the GWP emission intensities relating to each input to be sourced, and consequently enabling the overall environmental impact to be discretely calculated. The Process LCA methodology was employed to calculate the environmental impact using the equation below.

$$\textit{Environmental Impact} = \Sigma_{i=1}^{n} A_{p(i)} \times E_{p(i)}$$

The inputs (i) into the supply chain are represented by Ap, according to the constraints of the system boundaries. The total number of inputs (i) is given by n and the emission intensities of the GWP are given by Ep for each input (i) into the supply chain. The final units of this calculation are kg CO2-eq/tonne of landed seafood.

### Goal and Scope

The aim of this LCA is to determine the life cycle environmental impacts of salmon, mussels, oysters farmed and Atlantic mackerel, and *Nephrops* landed by the Irish seafood industry. These products are farmed and processed in Ireland prior to distribution for sale across the EU. The study has been completed to support the Irish seafood sector in their efforts to identify and subsequently reduce their environmental impacts and the intended application of this LCA is to consider the environmental impact of these systems in comparison with other seafood producing regions and to determine potential mitigation strategies to reduce the overall environmental impact. The results obtained in this assessment will not be reported in relation to any other seafood producing regions.

Aquatic food production can be split into two categories: capture fisheries and aquaculture. As such, different activities fall within the system boundaries of each of these categories. The system boundaries for each of the systems under consideration in this report are provided. Efforts have been made to ensure that the system boundaries are consistent within each seafood category. The environmental impacts of all five systems were determined from cradle-to-gate; in this case, "gate" refers to the harbour i.e., when the seafood is landed.

### Functional Unit

The functional unit provides a reference against which inputs and outputs to a system are normalised to allow for multiple systems to be evaluated on a common basis. Therefore, it is crucial that the functional unit is clearly defined and measurable. Despite this, functional units tend to differ significantly, and therefore making comparisons between results can be difficult (Ruiz-Salmon *et al.*, 2021). In this study, the functional unit applied to each of the five Irish seafood systems is defined as "1 tonne landed seafood". This aligns with the goal and scope of the study which aims to support the Irish seafood sector in their efforts to identify and subsequently reduce their environmental impacts.

### Omissions

The table below provides details regarding those processes, inputs and outputs that were omitted from the system boundaries including the justification and implications for their omission.

**Table 1:** Processes, inputs and outputs that were omitted from the system boundaries.

| Omission | Justification | Implication |
|---|---|---|
| Infrastructure e.g., vessels, machinery, etc. | Infrastructure lifespan is > 1 year (PAS 2050). | "Likely to be important" (PAS 2050-2) |
| Direct $N_2O$ emissions | Assumed minimal contribution to the overall impact (Hu *et al.*,). | "Likely to be insignificant" (PAS 2050-2) |
| Human energy inputs | Exclusion permitted from assessment (PAS 2050). | Insignificant (assumed) |
| Transportation of employees to and from their normal place of work | Exclusion permitted from assessment (PAS 2050). | Insignificant (assumed) |

The environmental impacts relating to the production of capital goods utilised in the aquaculture and fisheries life cycles, any human energy inputs, and the transportation of employees to and from their normal place of work, were excluded from the assessment. As the majority of production site/ landing port (including storage etc.) premises were built over 20 years ago, no emissions from land use change are included in this study.

### Life Cycle Inventory

This study collected primary Life Cycle Inventory (LCI) data from active parties in the Irish seafood supply chain. The details of the data collection for each species is detailed below under the LCA species development sections. LCI data is detailed within the LCA impact assessment spreadsheets. This data is believed to reflect the normal operating conditions of the Irish seafood sector and therefore is considered to be representative. An assessment period of three years was applied to both the capture fisheries and aquaculture systems (PAS 2050-2). Data was collected between 2017 and 2019.

Secondary data was collected from MOWI (operational and feed data) and EWOS (feed data). All other background data were sourced from Life Cycle Inventory database Ecoinvent v3.7.1 (2020), as per the requirements of PAS 2050.

# Lifecycle System Boundaries

- **Cradle to Farm Gate:** High level global carbon studies such as MacLeod *et al.*, (2020) do not include losses and emissions occurring post-farm and have prepared their global estimates on a 'cradle to farm-gate' spectrum. These focus on the primary production aspect of the life cycle and allow comparability between the carbon footprint of different aquaculture production systems and is independent of the downstream product processing and distribution chains. More recent studies have also focused on the primary production systems in aquaculture, such as Ghamkhar *et al.*, (2021) who examine the influence of production intensity on aquaculture LCAs. Of 56 aquaculture LCAs examined, 41 (73%) were from cradle to farm only (Bohnes & Laurent, 2018). Likewise, Philis *et et al.*, (2019) examined 24 LCAs for salmonid aquaculture, of which 18 (75%) were cradle to farm.

- **Cradle to factory gate:** the next level is from cradle (e.g., hatchery) to the first stage of primary processing and the entry of the product into the distribution chain (either for secondary processing or to the wholesaler and the consumer). Of the 56 aquaculture LCAs examined by Bohnes & Laurent (2018), 6 (11%) were cradle to factory gate (e.g., cradle to farm, plus processing and packaging).

- **Cradle to consumer:** Winther *et al.*, (2020) segregate the 'farming' process from the 'processing' and 'transport to market' stages in their recent review of greenhouse gas emissions of Norwegian seafood Products. Ziegler *et al.*, (2012, 2020) took a very different approach in their analysis of the carbon footprint of Norwegian seafood products on the global seafood market, identifying 22 main seafood product export chains, including farmed salmon by truck (to Paris, Oslo and Moscow), air (to Tokyo) and reefer container (to Shanghai). To make this manageable they modelled *"each species' supply chain as if produced by the same average Norwegian fishery for that species, which means that the results apply to theoretical "average" products rather than real products that can be found at a retailer"*. Iribarren *et al.*, (2010) also take a comprehensive business to consumer (B2C) approach for determining the carbon footprint of canned mussels from Galician rope mussel farms. In this case the authors examined the detailed LCA, focusing mainly on the ingredient input and transport elements, rather than the aquaculture production elements. Aubin *et al.*, (2018) also examined the LCA of blue mussel farming (from bouchet poles), examining the waste management post-consumer but left out the distribution, retail and consumption stages.

Of the 56 aquaculture LCAs examined by Bohnes & Laurent (2018), 9 (16%) were cradle to factory gate (e.g., cradle to farm, plus processing and packaging). Likewise, Philis *et al.*, (2019) examined 24 LCAs for salmonid aquaculture, of which 3 (12%) were cradle to (processing) factory gate.

Henriksson *et al.*, (2012) consider the options for setting system boundaries in aquaculture LCAs. They consider that the majority of focus has been on the cradle to farm gate stage but recognise that a substantial proportion of the entire carbon footprint for seafood is related to processing and distribution. Ultimately, they conclude that the selection of the system boundary should be consistent with the goal of the study, and the criteria used to establish the system boundary should be identified and explained (ISO 14044 2006; PAS 2050 (BSI, 2012)). In aquaculture systems, the length of the full production chain is largely dependent on the type of system (e.g., fed or non-fed aquaculture).

- **Inputs:** This section looks at the different inputs used by aquaculture LCAs to date, focusing primarily on those covering temperate aquaculture systems farming both salmonids (in marine and freshwater), bivalves (almost exclusively marine) and macroalgae (also mainly marine).

The processes and inputs that generate carbon in aquaculture production are very different to capture fisheries, although they may merge and even intermingle post-harvest. Bohnes & Laurent (2018) divide these up into a number of different stages (see figure below) and these are further examined in the following sections.

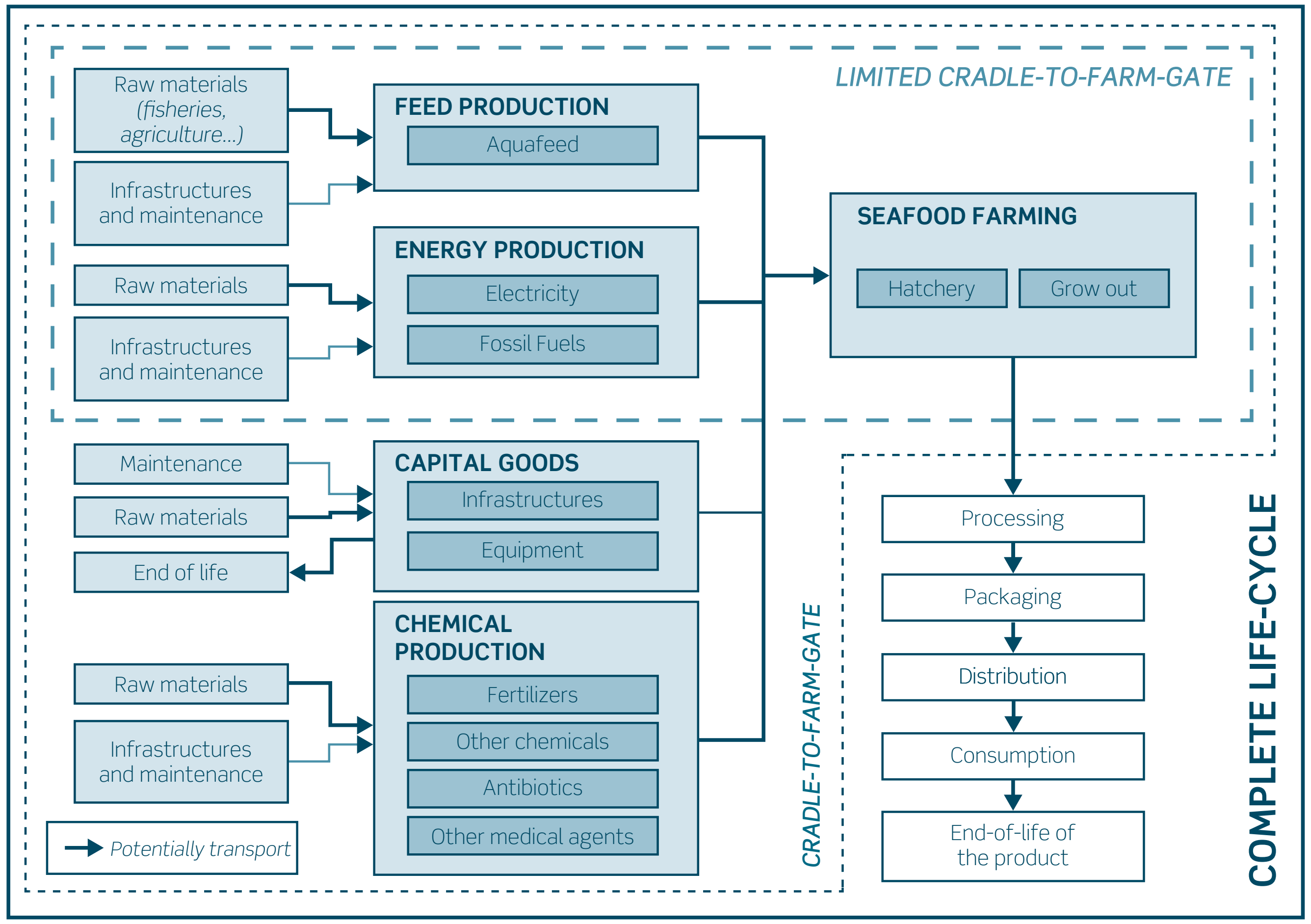


Figure 1: Different stages and processes of aquaculture production and types of system. Source: Bohnes & Laurent, 2018.

- **Aquafeeds:** Aquafeeds in this context refer to compounded diets for finfish such as salmon and trout. Feed provision accounts for the majority of material and energetic inputs and emissions associated with sea pen-based salmon farming (Pelletier & Tyedmers, 2007) which accounts for almost a third by volume of Ireland's aquaculture outputs. Salmonid aquafeeds - which are designed to provide fish with protein to grow as efficiently as possible, as well as various lipids and carbohydrates to support metabolism and thus are typically formulated with fishmeal, fish oil, soyabean meal concentrate, canola products, wheat, and other ingredients, all of which have various production processes and transport chains.

  Mowi, one of the main producers in Ireland, have calculated their emissions in connection to sourcing feed raw materials for their feed business following the Aquaculture Stewardship Council (ASC) guidelines for GHG accounting of feed, the GHG Protocol Standard and the carbon footprint of feed raw materials provided by SINTEF (Gabrielii & Jafarzadeh (2020) 'Carbon footprint of fisheries - a review of standards, methods and tools' and estimated a production of 161 kg to 170 kg CO2e/tonne of feed produced (MOWI, 2020). They recently completed a project with LCA experts to update the carbon footprint of all their feed raw materials and include that information in their formulation program.

  One key consideration is that currently all of Ireland's salmon production is exclusively produced to the EU Organic Certification Standard (EC, 2007). Ireland is by far the leading producer of organic aquaculture species with an EU production share of 42%, followed by Italy (16%) and France (8%). Certification standards, such as those by Naturland (Naturland, 2020) require that animal components of the feed are replaced by vegetable products and that the percentage of fishmeal/-oil is decreased in the feed composition as far as possible. Organic feeds may also use white fish processing waste to reduce fishmeal use, but this may have consequences for the carbon footprint of these relatively low-volume commodities.

  This may have consequences for the carbon footprint of Irish organic salmon versus other non-organic salmon from Norway, Scotland, or Chile. However, Pelletier & Tyedmers (2007) found that substituting organic for conventional crop ingredients resulted in only minor improvement to the environmental performance of feed production. This was due to the much larger impacts associated with the production of animal-derived ingredients, which overwhelmed the gains associated with organic/conventional crop substitution.

  MacLeod *et al.,* (2020) used emissions factors (EFs) for crop feed materials were based on the values derived from FAO's Global Livestock Environmental Assessment Model (GLEAM). Regional average values were used for each feed, meaning that the EFs at least partially capture variation in crop production efficiency between regions. EFs for additional feeds (e.g., fish meal, poultry meal, feather meal, meat & bone meal, blood meal, groundnut meal) were derived from Feedprint. Non-commercial feed materials were assumed to be produced locally and have different emission profiles to their commercial equivalents (e.g., no emissions from transport).

  Another factor is Food Conversion Ratios (FCRs), the relationship in biomass terms of weight of food fed and weight gain achieved. Obviously the more efficient the FCR, the less feed and related GWP is required. Seafood production yields lower FCRs compared with other farmed terrestrial animals, indicating higher harvest yields for aquatic species. However, specific FCRs for seafood production depend on many factors such as diet type, species, and the harvesting environment characteristics (Ghamkhar & Hicks, 2020).

## Energy

Energy is required throughout the aquaculture LCA, both for the preparation of raw materials (e.g., aquafeeds) and facilities, as well as in the actual aquaculture production process itself. It is of course a major need for post-harvest processing and distribution. As a key input into transportation, it is also one of the key variables that need to be considered in cradle to consumer LCAs when long distance travel is required, especially for chilled material travelling by air.

Our focus here is on the cradle to farm gate system for which the key energy inputs are described in more detail in the appendices covering feed production, transport (vessels and terrestrial vehicles), capital goods and chemical production.

- **Feed production:** aquafeeds have comprehensive processes in their own right, including:
  - Fuel and other energy costs for the wild harvest of forage fish for reduction into fishmeal & fish oil.
  - The forage fish reduction process is also energy demanding. However replacing fishmeal / oils from dedicated reduction fisheries with fisheries by-product meals/oils markedly increased the environmental impacts of feed production, largely due to the higher energy intensity of fisheries for human consumption, and low meal/oil yield rates of fisheries by-products (Pelletier & Tyedmers, 2007).
  - The growing and harvesting of terrestrial proteins and carbohydrates used in fish feeds.
- **Fossil-fuel usage:** fossil fuels are used for both water and terrestrial transport across an aquaculture LCA. The key inputs into aquaculture include:
  - Fuel for vessels involved in 'catch and hatch' aquaculture e.g. the capture and relaying of mussel seed and their subsequent harvest in bottom mussel farming operations.
  - Fuel for workboats transporting stock, feed, equipment and personnel to and from offshore installations.
  - Fuel for generating electricity in remote locations e.g. offshore pen sites to run feeding equipment, stock monitoring IT infrastructure, etc.
  - Fuel for terrestrial vehicles (4x4s, tractors & all terrain vehicles) servicing aquaculture operations in the intertidal and shallow sub-tidal areas e.g. for oyster trestle husbandry.
  - Generation of electricity for main grid supplies to land-based aquaculture e.g. hatcheries, nurseries and re-circulating aquaculture systems (RAS) systems.
- **Capital goods:** Like most production systems, aquaculture requires considerable capital goods in the form of infrastructure, such as stock containment systems (ponds, pens, etc., mooring systems (ropes, buoys anchors, vessel support and other capital assets. Ziegler *et al.,* (2012) included post-factory gate transport in their Norwegian seafood LCAs but excluded the construction of fishing vessels and gear and presumably (but not stated) aquaculture grow-out infrastructure. Infrastructure is also often excluded due to the large amount of time that has to be invested in calculating the total input in relation to the small impact that is considered (Ayer and Tyedmers, 2009).

  Where included and distinguished infrastructure was found to contribute between 0% and 19.0% to the overall impacts in terms of global warming, eutrophication, and acidification indicators (Henriksson *et al.,* 2012). Pen-based farming LCAs often ignore infrastructure such as pen collars as they are considered light in weight (Philis *et al.,* 2019), ignoring the fact that considerable quantities of high-density polyethylene (HDPE) maybe used in their construction (Huntington, 2019). This suggests that future LCA standards should be included in future product environmental footprint (PEF) compliant LCAs.

- **Chemical production:** a number of chemicals, chemotherapeutants and reagents are used in Irish aquaculture such as oxygen, disinfectants, lice treatments and antibiotics. Nutrient inputs may also be required by macroalgae culture in Ireland if a hatchery sub-sector were to be developed. Many aquaculture LCAs (c.40% according to Bohnes & Laurent, 2019; Bohnes *et al.*, 2018)) ignore these inputs, mainly because of the expected negligible impacts these may have (<5% contribution according to many studies) or the lack of primary data and available databases to support consistent modelling.

## GHG outputs

This section looks at the greenhouse gas (GHG) outputs from aquaculture. The major GHGs associated with aquaculture production are:

- **$CO_2$ (carbon dioxide)** arising from pre-farm energy use (primarily associated with feed and fertilizer production), on-farm energy use (e.g. pumping of water, use of electricity, other fuel consumption) and during post-farm distribution and processing. $CO_2$ emissions also arise from changes in above and below ground carbon stocks induced by land use and land use change (LUC) (primarily driven by increased demand for feed crops, which can lead to the conversion of forest and grassland to arable land).
- **$N_2O$ (nitrous oxide)** arising from the microbial transformation of N (nitrogen) (mainly from applied fertilizers) in soils during the cultivation of feed crops. Significant amounts of $N_2O$ may also be emitted from ponds as a result of the microbial transformation of nitrogenous compounds in ponds (e.g. synthetic fertilizers, manures, composts, uneaten feed and excreted N), although the magnitudes of these emissions are less readily quantified.
- **$CH_4$ (methane)** arising mainly from the anaerobic decomposition of organic matter during anaerobic digestion e.g. in seaweed processing (Czyrnek-Delêtre *et al.*, 2017). May also arise during fish farm waste management.
- **F-gases (fluorinated gases)** - small amounts of these potent greenhouse gases are leaked from cooling systems on-farm and post-farm.

MacLeod *et al.*, (2020) conducted a high-level, global study and estimated that in Western Europe salmonids produced around 2.7 kgCO2e per kg of fish and bivalves 1.02 kgCO2e per kg of shellfish.

Those greenhouse gas (GHG) sources not included in the 'cradle to farmgate' system boundary are listed in the table below.

**Table 2:** GHG sources not included within the 'cradle to farm-gate' system boundary.

| Process | Gas | Comment |
|---|---|---|
| Energy in the manufacture of on-farm buildings and equipment (including packaging) | $CO_2$ | Difficult to quantify, unlikely to be a major source of emissions |
| Production of cleaning agents, antibiotics, and pharmaceuticals | $CO_2$ | Unlikely to be a major source of emissions |
| Anaerobic decomposition of organic matter from biofilters | $CH_4$ | Difficult to quantify, unlikely to be a major source of emissions |
| $N_2O$ from the animal | $N_2O$ | Possibly significant for invertebrates, but difficult to quantify |
| $CO_2$ sequestered in carbonates | $CO_2$ | Possibly significant for invertebrates |
| Leakage of coolants | F-gases | Difficult to quantify, potentially significant (particularly post-farm) |

## Metabolism and Biological Waste Production

Nitrogen is an important component of protein, and thus of protein rich aquafeeds. Not all of this protein is consumed by fish growth, with excess nitrogen egested as faeces, or as pseudo faeces by shellfish, and unionised ammonia through the gills. Unconsumed feed and faeces contribute to the organic load of aquaculture. This can be converted to nitrogen gases ($N_2$ & $N_2O$) through nitrification and denitrification processes. Nitrous oxide ($N_2O$) is an important GHG which has a global warming potential 310 times that of carbon dioxide ($CO_2$) over a hundred year lifespan. $N_2O$ is generated during microbial nitrification and denitrification, which are common in aquaculture systems. Hu *et al.*, (2012) estimate salmonid aquaculture production to produce around 1.7 kg $N_2O$-N per tonne of fish (e.g., c. 0.5t $CO_2$-e / tonne). However, MacLeod *et al.*, (2020) note that estimates of aquatic $N_2O$ should be treated with caution, as the rate at which N is converted to $N_2O$ in aquatic systems can vary greatly, depending on the environmental conditions. It has been noted that nitrification and denitrification processes are influenced by many parameters (e.g., dissolved oxygen concentration, pH, temperature).

## Carbon Sequestration by Aquaculture Systems

It should also be considered that some forms of low-trophic aquaculture may have the potential to sequester carbon e.g., through the production of calcium carbonate shells which are stable on geological timescales (Smaal *et al.*, 2019), although this is currently being contested (Morris & Humphries, 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).

Jansen & van den Bogaart (2020) recently modelled the carbon sequestration of blue mussel production in the Netherlands and found it may result in a positive value (max ~1,000g C per production cycle) or in a net release (minimum -500g C per production cycle), indicating a threefold difference in the way it is estimated. This equates to respectively 4,000 or -3,500 tonnes C y-1 when these numbers are translated to the entire Dutch mussel sector. They concluded that none of the approaches examined were sufficient to address all/essential ecosystem processes and therefore suggested that the ecosystem approach should be applied to evaluate carbon fluxes related to shellfish production and that models should at least include interactions with phytoplankton populations, but also all metabolic processes related to bivalve growth (such as feeding, respiration, growth, (pseudo) faeces production and decomposition).

Given this and the findings of MacLeod (2020) mentioned above, we conclude it is not appropriate to include $CO_2$ sequestered in carbonates for blue mussels at this stage. However, we should consider including the storage of carbon in oyster shells, as their use on land in the form of road hardening material or in land drainage systems may well last more than 100 years, even though volumes are not major. The carbon footprint calculations for mussels and oysters that are applied here follow the guidance as set out in PAS 2050-2:2012 (BSI, 2012).

## Unit Process 1: Aquafeed Production

The manufacture of aquaculture feeds (aquafeeds) from their raw materials into a pelleted feed ready for delivery to the farm. Most aquafeeds consist of a fishmeal / oil component, which itself is obtained by reducing small pelagic fish into a dried meal. Other feed components, e.g., soymeal and wheat, come from terrestrial farming systems.

Terrestrial crop production: Growing and harvesting of crops on land for subsequent processing (e.g., milling) as raw materials for aquafeeds.

Raw material processing: The processing of (i) forage fish and (ii) terrestrial crops. In the case of forage fish this is normally an industrial reduction process that uses heat and pressure to extract the protein and oil content of fish as raw ingredients for aquafeeds.

## Unit Process 2: Aquaculture Production (land)

The process of spawning, on-growing, and harvesting aquatic animals.

Hatchery: A specialist unit where broodstock (parent fish) are held and spawned. The male and female gametes are mixed, and the fertilised eggs are kept until they hatch, and the yolk sacs utilised.

Fingerling (parr) nursery: Once the yolk sacs have been absorbed, the fish are grown as fingerlings (literally finger-sized fish). In the terms of salmon these are call 'parr'. This stage is entirely freshwater based and is usually undertaken in a controlled environment inside a building.

Smolt production (land-based): As salmon grow, they adapt to move from fresh-water to seawater. This requires a number of profound physiological adaptions that is referred to as smoltification. Traditionally, smolts are transferred to sea water at around 100 g, but they may be held in land-based units (using controlled salinities as the smoltification process proceeds) to reduce their overall time at sea (so-called "super smolts").

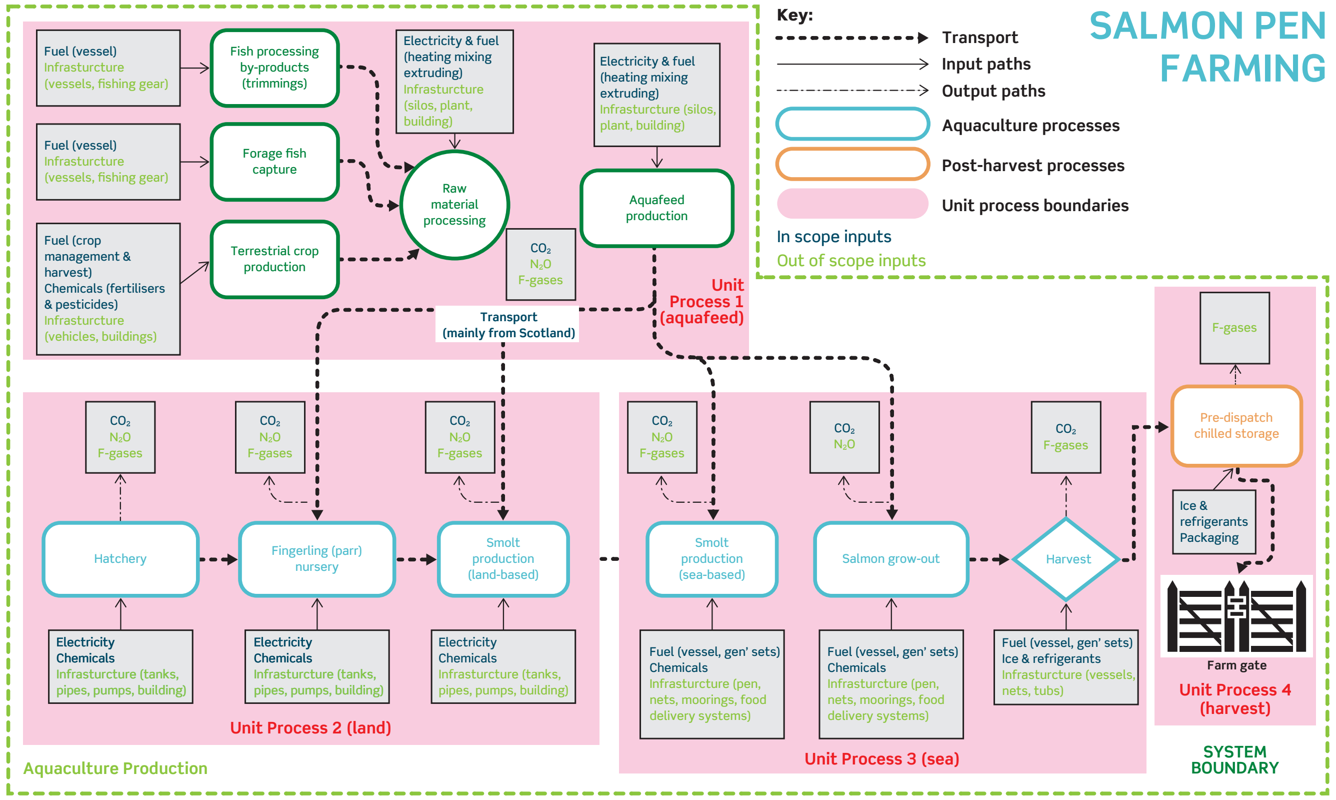


**Figure 2:** LCA system boundary - Atlantic Salmon.

## Unit Process 3: Aquaculture Production (sea-based)

Smolt production (sea-based): At the appropriate time, the smolts will be transferred to pens in the sea until they become "post-smolts".

Salmon grow-out: The main grow-out period where the post-smolts are held until they reach harvest size, a process that can take several years. During this time, the fish will be fed, occasionally graded and their health and welfare maintained.

## Unit Process 4: Harvest

The process by which the fish are removed from the cages and killed in preparation for sale.

Pre-dispatched chilled storage: Once the fish have been harvested, they are usually placed in large bins or harvest containers with chilled water before being transported back to shore, packed in boxes with ice, and maintained in a chilled (refrigerated) room before they leave the processing premises.

## Direct Emissions

The direct emissions from salmon aquaculture are varied in both terms of source and scale. They can be briefly summarised below:

- **$CO_2$ (carbon dioxide)** arising from pre-farm energy use (primarily associated with aquafeed production), on-farm energy use (e.g. feed transport, support vessel fuel consumption, use of electricity, other fuel consumption) and during post-farm distribution and processing.
- **$N_2O$ (nitrous oxide)** arising from the microbial transformation of N (nitrogen) (mainly from applied fertilizers) in soils during the cultivation of feed crops (e.g. wheat for use in organic aquafeeds). $N_2O$ may also be emitted from ponds as a result of the microbial transformation of nitrogenous compounds in sediments below the pens (e.g. from uneaten feed and excreted N), although the magnitudes of these emissions are less readily quantified.
- **F-gases (fluorinated gases)** - small amounts of these potent greenhouse gases are leaked from ice production, cooling or freezing systems on-farm and post-farm.

## Wastes

With salmon farming in Ireland operating on a larger scale than other aquaculture sub-sectors, waste tends to be minimised through the use of bulk transport, especially in terms of feed transport and delivery to the fish. The main wastes from aquaculture include:

1. Biological waste from fish stock mortalities. These are currently treated as Category 1 animal by-products (they are actually Category 2 products, but there are currently no Category 2 waste management facilities in Ireland) and are rendered into meal, protein and oil at plants approved by the competent national authority in accordance with European Commission Regulation No 1069/2009.
2. End of life equipment. Some parts of the farming equipment have higher replacement rates than others, especially netting, ropes and consumables such as plastic gloves.

# Rope Grown Mussels

Irish rope-grown mussels mainly use the native blue mussel which is a low trophic marine bivalve, mainly with the traditional surface longline system (200m double headrope supported on the surface by approximately 30 standard floats, 210 litres in volume and anchored at each end. The mussels attach by their byssus threads to drop ropes hung in the water column at intervals from the head rope). Around 11,672 tonnes of mussels were grown in Ireland in 2021 using ropes suspended in the water column. Collector ropes are hung out between April and June, depending on the bay to catch mussel larvae ('spat') naturally occurring in the water. Grow out time from seed to harvest is about 2 years. They do not need artificial feed, as they filter the surrounding seawater for growth.

As mentioned there will be differences in mussel farm production technology (e.g. the traditional surface longline system or the more modern 'New Zealand' continuous longline system) and the differing levels of husbandry around the Irish coast e.g. a number of bays in the southwest and west (Ardgroom, Kilmakillogue, Killary, Galway Bay) still adopt more traditional methods of seed collection using different types of collectors and never stripping the lines. They would therefore likely have a very different carbon footprint.

## Unit Process 1: Seed Mussel Collection at Sea

Seed mussel collection is the collection of natural spat (free-living mussel larvae) onto an artificial substrate, normally 'hairy' ropes suspended in the water column. The collected spat are then stripped off for repacking onto grow-out ropes at sea, usually in the same bay area.

## Unit Process 2: Grow-out at Sea in New Zealand Continuous Longline System

The naturally collected spat are harvested from the seed collector rope, graded into size categories, and repacked at a specific stocking density per metre of rope held in place by biodegradable cotton mesh.

## Unit Process 3: Grading and Harvest

After 18-24 months at sea the mussels are harvested. This is the typical timeframe in Irish waters, although in other waters it can take three years. A specially equipped vessel is used to grade off under-size / broken mussels and harvest the market-size mussels for transfer to the shore. Grading is undertaken at sea and undersized animals are reseeded while any mortalities are disposed of and not recorded.

## Unit Process 4: Depuration

Mussels are placed in a land-based seawater tank system with ultraviolet lighting to kill pathogens and purge the mussels in preparation for human consumption. Depuration is required for mussels going into the fresh market. It is not required for mussels being sold for processing.

## Unit Process 5: Packing and Pre-departure Storage

The depurated mussels are packed into 1 tonne bags for processing in Irish or Dutch plants or into 15kg onion bags for the fresh market.



## Direct Emissions

The direct emissions from rope mussel farmed are limited, both in terms of source and scale. They can be briefly summarised below:

- **$CO_2$ (carbon dioxide)** arising from pre-farm energy use, on-farm energy use (e.g. support vessel fuel consumption, use of electricity, other fuel consumption) and during post-farm distribution and processing.
- **$N_2O$ (nitrous oxide)** arising from the rope farming of mussels is lower than that of finfish (e.g. salmon, see above) but dense populations of filter feeders greatly enhance rates of sedimentation of particulate organic matter, which is actively removed from the water column and deposited to the sediment as faeces and pseudo-faeces. This may lead to higher organic matter loads which may increase sediment oxygen demand (SOD) and N release.
- **$CH_4$ (methane)** arising mainly from the anaerobic decomposition of organic matter.
- **F-gases (fluorinated gases)** - small amounts of these potent greenhouse gases are leaked from ice production, cooling or freezing systems post-harvest.

## Wastes

The main wastes from rope-grown mussel farms include:

» Mussel shells: mostly disposed of *in situ*.

» Biological waste from grading. These may be processed through composting or processed at Category 3 approved animal by-product treatment plants. Grading at sea mostly disposed of *in situ*.

» End of life equipment. Some parts of the farming equipment have higher replacement rates than others, especially ropes and consumables.

## ROPE-GROWN MUSSELS

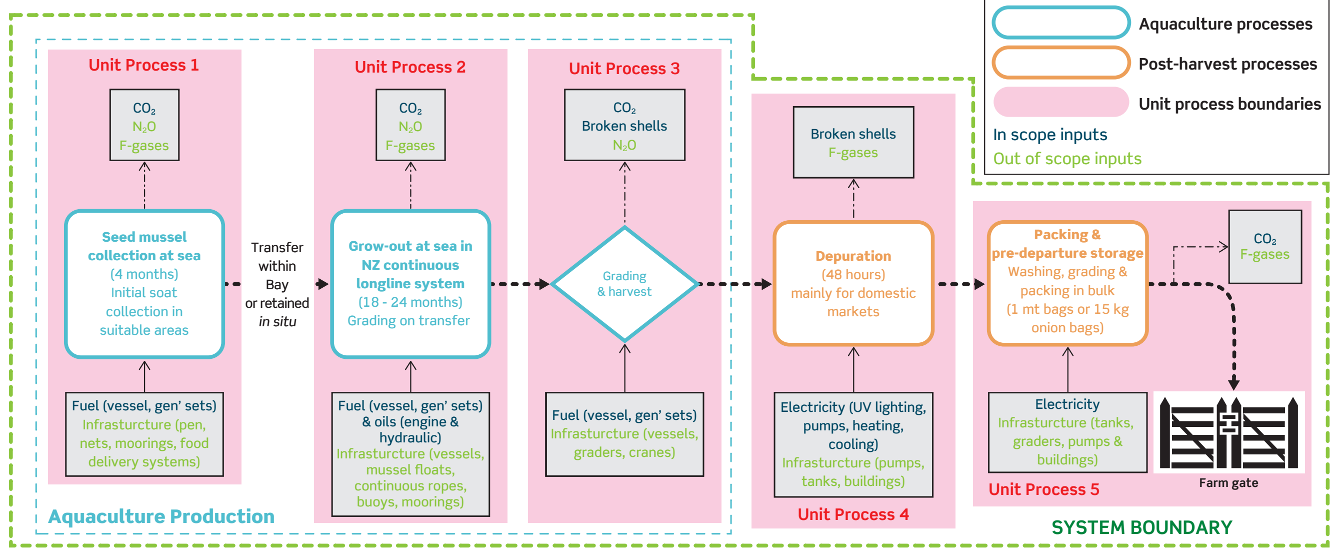


**Figure 3:** System boundary - Rope-grown Mussels.

# Trestle Grown Oysters

Oysters are a low-trophic species. Like other major European producers such as France, Irish oyster farming is of the Pacific oyster. It is mainly farmed in plastic mesh bags secured onto steel trestles placed in the inter-tidal zone. With around 10,624t of Pacific production in 2021 it is an important species for SMEs in Irish aquaculture. They do not need artificial feed, as they filter phytoplankton from the surrounding seawater for growth. The system boundaries, including typical division of Unit Processes.

## Unit Process 1: Hatchery / Nursery

A specialist unit where broodstock (parent shellfish) are held and spawned (both diploid and triploid oysters are produced). The male and female gametes are mixed, and the fertilised eggs kept until they settle and are ready for grow-out. The broodstock, larvae and settled spat are fed specific strains of microalgae produced in continuous systems in the hatchery. Hatcheries supplying to the Irish market are mostly in France; there are also two Irish hatcheries and two UK hatcheries that supply a very small percentage of the Irish market.

## Unit Process 2: Nursery (land-based)

An intermediary nursery stage where oysters are grown in controlled conditions on land before transfer to the sea. Spat are raised outdoors at high densities in upwellers in flow through nurseries. They can either depend on the naturally occurring microalgae in the pumped seawater or, is the case in the vast majority of nurseries, the microalgae is produced in separate systems, usually outdoor tanks, and added to the seawater.

## Unit Process 3a: Grow-out (inter-tidal)

The juvenile oysters are placed in mesh bags on trestles in the inter-tidal zone for on-growing over a 24 – 36-month period. This lifts the bags off the ocean floor and allows the water to flow around them helping them to grow faster and keeping them away from predators like crabs and birds. While submerged the oysters turn with the tides. At low tide the farmer is able to access the trestles to turn the bags. This regular flipping prevents fouling building up on the bags and stops the oysters from growing into the bags and one another.

## Unit Process 3b: Grading/Sorting Operations (land-based)

During the "grow-out" period, the oyster bags are moved to a land-based unit for sorting, grading and re-bagging before being transferred back to the grow-out trestles.

## Unit Process 4: Harvest

The bags are transferred to an adjacent land-based facility for sorting to remove under-sized / damaged oysters for depuration.

## Unit Process 5a: Depuration

Oysters are placed in a seawater tank system with ultraviolet lighting to kill pathogens and purge the oysters in preparation for human consumption. If exported depuration usually takes place in the country of destination.

## Unit Process 5b: Packing and Pre-departure Storage

The depurated oysters are washed, graded, and packed for market.



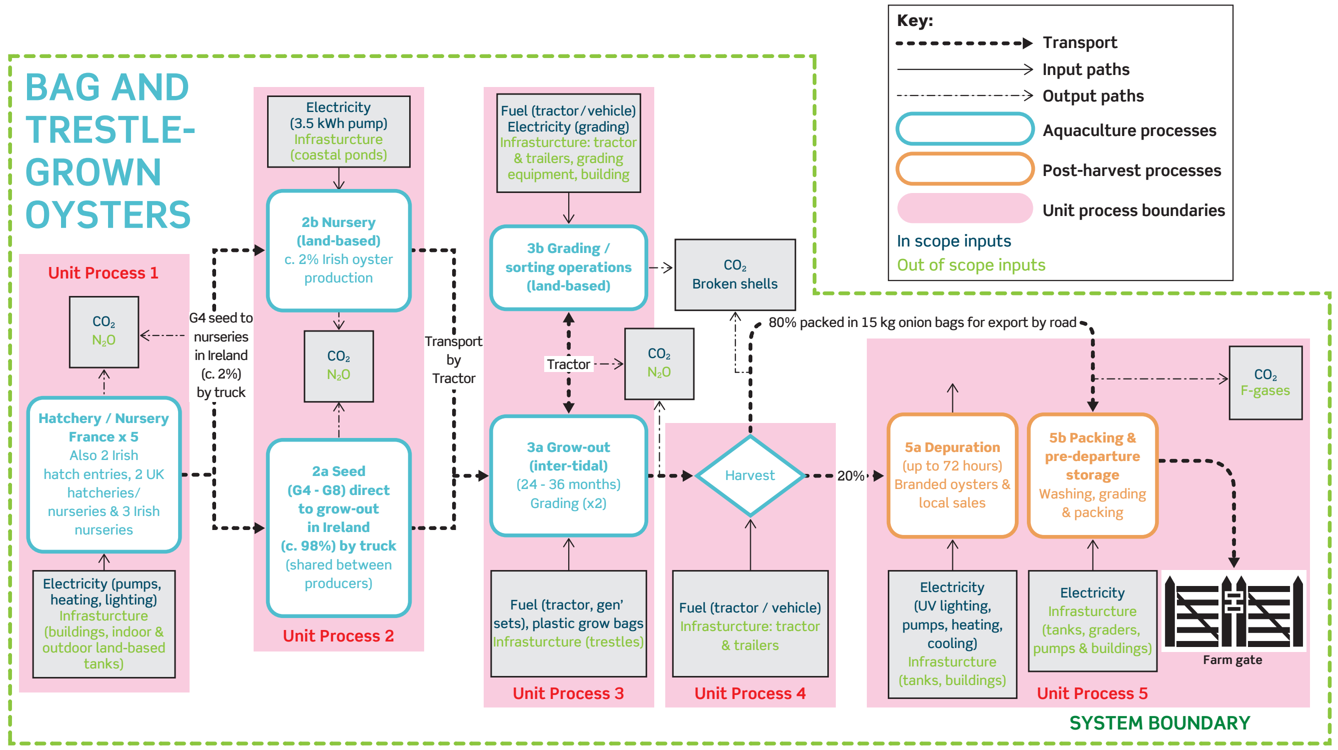


Figure 4: System boundary - Gigas Oysters.

## Direct Emissions

The direct emissions from trestle-grown oysters are limited, both in terms of source and scale. They can be briefly summarised below:

- **$CO_2$ (carbon dioxide)** arising from pre-farm energy use, on-farm energy use (e.g. support vehicle fuel consumption, use of electricity, other fuel consumption) and during post-farm distribution and processing.
- **$N_2O$ (nitrous oxide)** arising from the trestle farming of oysters is lower than that of both finfish (e.g. salmon) and mussels as are usually in lower densities. However they may result in enhanced rates of sedimentation of particulate organic matter, which is actively removed from the water column and deposited to the inter-tidal sediment as faeces and pseudo-faeces. These high organic matter loads may increase sediment oxygen demand (SOD) and N release.
- **$CH_4$ (methane)** arising mainly from the anaerobic decomposition of organic matter.
- **F-gases (fluorinated gases)** - small amounts of these potent greenhouse gases are leaked from ice production, cooling or freezing systems on-farm and post-farm.

## Wastes

The main wastes from trestle-grown oysters include:

» Oyster shells and mortalities: sometimes crushed for use on unmetalled roads or used to improve land drainage. Some farms sell their shell for use in bio-filtration systems where it is mixed with other shell and crumb rubber (see https://anuacleanair.com/wp-content/uploads/2017/09/datasheet.pdf).

» End of life equipment. Some parts of the farming equipment have higher replacement rates than others, especially oyster bags, cable ties and consumables such as plastic gloves.

# Salmon LCA Approach

Due to the relatively complicated life history of salmon, as well as its dependence upon artificial food for sustenance and growth, the approach to determining the carbon footprint of salmon is the most complicated of the three species/systems covered.

There are three key stages involved:

- Development of functional unit model
- Data gathering
- LCA development

## Development of functional unit model to calculate inputs/outputs for 1 tonne salmon

The purpose of this LCA is to estimate the GWP of one tonne of live weight salmon at the farm gate. To do this we had to construct a simple model that allows us to estimate the inputs and outputs at the beginning and end of each Unit Process (UP).

The key inputs are:

- The number and biomass of livestock at each UP e.g. (eggs at UP 2, smolts at UP 3 and finished salmon at UP 4).
- The volume of feed used to produce 1 t salmon, including over the land-based smolt production phase (UP 2) and sea-based grow-out stage (UP 3).

The key outputs are:

- The number of finished salmon in the functional unit (1 tonne of salmon).
- The biomass of mortalities in each UP the functional unit, e.g. over the land-based smolt production phase (UP 2) and sea-based grow-out stage (UP 3).

The key variables that need to be included in the model include:

- Egg / fish sizes at the different stages e.g. UP 2 & UP 3.
- Food conversion ratios e.g. UP 2 & UP 3.
- Mortality rates on land and at sea e.g. UP 2 & UP 3.
- Feed raw materials in UP 1.

It should be noted that the GWP for the feeds in UP 1 is based on detailed LCAs produced by Asplan Viak in Norway for the two main feeds used in Irish organic aquaculture e.g.:

- Freshwater UP 2: Cargill starter feed (< 3 mm) sourced from Bathgate in West Lothian, Scotland.
- Seawater UP 3: MOWI (9 mm) GAIA 1200 feed, sourced from the Isle of Skye, Scotland. Key raw material components are (i) fish meal trimmings (43.7%), (ii) fish oil (17.7%) and organic peas & beans (18.6%).

## Data Gathering

The key data gathered included:

- Inputs and outputs industry data on production over 2017 – 2020.
- Other GWP generators e.g.
  - Feed transport volumes, methods and routes
  - Consumable use (therapeutants, vaccines, cleaning agents, equipment replacement)
  - Waste treatment methods, routes and distances.
  - Electricity usage
  - Fuel usage by vehicles and boats
  - Harvest and post-harvest elements e.g. water, ice production, refrigeration.

For data confidentiality reasons the names of the industry sources cannot be disclosed, but the data provided covers over 80% of Irish organic salmon production. The data gathering approach included the preparation of data requirement sheets, face to face interviews with key industry management and follow-up communication.

## LCA Development

Once the industry data was received, the functional unit model was populated to generate the key data to enter into the LCA models.

# Rope-grown Mussels LCA Approach

The continuous longline “New Zealand” system for growing mussels is comparatively straightforward and requires only a small amount of active management. Blue Mussels have a simple life history which is completed within the single habitat. There is one thinning process undertaken and no artificial feed inputs. Stocking densities are controlled by line placement.

The culture of the mussels involves provision of a large area of suitable foreshore which is easy to harvest. The reference sites all collect spat locally, usually adjacent to or within the same bay as the farm. There are therefore no significant inputs to the process, and unlike the salmon LCA no modelling is required to account for mortality or transfers between Unit Processes.

## Data Gathering

The key data gathered included:

- Fuel use by boats and harvest equipment.
- Oils and coatings used on boats and harvest equipment.
- Raw cotton wrap.
- Polypropylene packaging.

## LCA Development

Once the industry data was received, the functional unit model was populated to generate the key data to enter into the LCA models.

# Trestle-grown Oysters LCA Approach

Pacific Oysters have a simple life history which is completed within the single habitat. Cultivation of the Pacific Oyster in Ireland by the trestle method involves the provision of a protected environment to concentrate the oysters and make harvesting easier. The oysters are typically sourced from France at G4-G8 size (2 months, 0.04g - 6 months, 0.14g), with the reference sites contacted all purchasing G8 seed which does not require a nursery stage. The grow out and grading typically takes place in the same bay and the equipment used is not separated in the records. As a result, Unit Processes 2, 3 and 4 have been considered together. Depuration takes place at the farm for all reference sites.

## Data Gathering

The key data gathered included:

- Fuel use by tractors and other harvest equipment.
- Electricity used in depuration, cleaning and grading.
- Polypropylene packaging.

# Methodology - Wild capture fisheries

## Wild capture LCA Literature Review and LCA System Boundaries

- **Cradle to "farm gate":** Two recent studies have performed an extensive review of the available literature on life cycle analysis of capture fisheries. Avadí *et al.,* (2020) published an LCA review where the main objective was to present the first effort to aggregate and standardize seafood related datasets in the Ecoinvent database. Ruiz-Salmon *et al.,* (2021) reviewed 59 relevant journal articles and produced an analysis of the content. Six of these studies focus on cultured mussels and are not considered in this section. Some of the 53 studies included more than one analysis, with a total of 39 (74%) conducted as cradle to "farm gate" or landing of the catch and transfer to the customer. The system boundaries typically included at least the use and maintenance of the vessel while ten (18%) also included the construction of the vessels. However, three of these were by the same authors on different species in the same year, so could be considered together. Beyond vessel-related activities, the systems commonly end at the harbour, when fish is landed. Almeida *et al.,* (2015), and Avadí *et al.,* (2018), included both the fishing stage and the processing stage.

  Avadí & Fréon (2015) report that of 19 studies primarily conducted in the East and Northeast Atlantic only one included the construction of the vessel. The review focuses on capture activities and therefore excludes processing, but eight of the studies included processing operations clearly separated from the capture phase. Sandison (2021), identified as the best analogue of this study in those reviewed, includes construction of the vessels.

- **Cradle to factory gate:** The next level is from cradle (e.g., hatchery) to the first stage of primary processing and the entry of the product into the distribution chain (either for secondary processing or as is to wholesale and the consumer). Seven of the 53 (13%) studies in Ruiz-Salmon *et al.,* (2021) utilised this system boundary. Svanes *et al.,* (2011) included transport to the processing factory, but this was of frozen processing residue going to feed production. Laso *et al.,* 2017 focused on production of anchovy canned in olive oil and examined individual stages from cradle to factory gate as well as gate to gate (processing).

- **Cradle to grave:** Seven of the 53 (13%) studies in Ruiz-Salmon *et al.,* (2021) considered the full cradle to grave impacts. Fréon *et al.,* (2017) included fishing effort in the production of fishmeal and fish-oil as co-products. Of these, five focussed on processed fish while two were of a specific Business to Consumer (B2C) relationship with a specified processor which reduced the system complexity significantly.

## Functional units

The functional unit is the basis of comparison in comparative LCAs. The functional unit is the reference unit used to quantify the performance of a production system (ISO 14044, 2006). The most commonly used functional unit in capture fishery LCAs (56% of those identified by Ruiz-Salmon *et al.,* (2021)) is 1 tonne of live fish at the quayside (see below for system boundary scoping). Species targeted by studies in this review included demersal finfish (Abdou *et al.,* (2018)), Peruvian Hake (Avadí *et al.,* (2018)), and European Pilchard (Villanueva-Rey *et al.,* (2018)). Alternative functional units were based on processed commodities, e.g., kg of tinned anchovy.

## Inputs

This section looks at the different inputs used by capture fishery LCAs. LCAs that have previously been undertaken for modern fisheries generally indicate that the capture process is the single most significant factor contributing to emissions over a product's entire lifespan (Avadí and Fr'eon, 2013; Hilborn *et al.,* 2018), though its significance varies from fishery to fishery (Ziegler and Valentinsson, 2008).

- **Energy:** Diesel is used to power the vessels at sea.
- **Consumables:** materials and products required for the upkeep and maintenance of the equipment used to fish:
  - Oils and chemicals used in the maintenance of the equipment and vessel hulls.
  - Materials for the repair and upkeep of the nets and lines.
  - Additives and preservatives.
  - Packaging for protection during transport.
- **Capital goods:** Infrastructure such as the vessel is often excluded due to the large amount of time that has to be invested in calculating the total input in relation to the small impact that is considered (Ayer and Tyedmers, (2009)). In addition, PAS2050-2 states that capital goods such as buildings and vessels should be excluded.

**Table 3:** GHG sources not included within the 'cradle to farm gate' system boundary.

| Process | Gas | Comment |
|---|---|---|
| Energy in the manufacture of vessels and gear | $CO_2$ | Difficult to quantify, unlikely to be a major source of emissions - note 96% finding in Sandison. |
| Production of cleaning and antifouling agents. | $CO_2$ | Unlikely to be a major source of emissions. |
| $CO_2$ released from sediments during demersal drawl | $CO_2$ | Depends on gear and substrate, difficult to rationalise. |
| Leakage of coolants | F-gases | Most on-board systems use ammonia, leakage rates unknown. |

## Greenhouse Gas (GHG) outputs

This section looks at the GHG outputs from fisheries. The major GHGs associated with capture fisheries are:

- **$CO_2$ (carbon dioxide)** arising from combustion of fuel in engines and machinery. Sandison (2021) found the emissions from fuel consumption to be approximately 96% of the total carbon emissions.
- **$N_2O$ (nitrous oxide)** arising from combustion of fuel in engines and machinery.
- **F-gases (fluorinated gases)** - small amounts of these potent greenhouse gases are leaked from cooling systems on board. Sandison (2021) found the leakage rate to have little impact on any of the measured impacts.

## Nephrops LCA Omissions

Table 4 provides details regarding those processes, inputs and outputs which were omitted from the system boundaries including the justification and implications for their omission.

**Table 4:** Processes, inputs and outputs omitted from the system boundaries

| Omission | Justification | Implication |
|---|---|---|
| Infrastructure e.g., vessels, machinery, etc. | Infrastructure lifespan is > 1 year (PAS 2050). | "Likely to be important" (PAS 2050-2) |
| Direct $N_2O$ emissions | Assumed minimal contribution to the overall impact (Hu *et al.*,). | "Likely to be insignificant" (PAS 2050-2) |
| Human energy inputs | Exclusion permitted from assessment (PAS 2050). | Insignificant (assumed) |
| Transportation of employees to and from their normal place of work | Exclusion permitted from assessment (PAS 2050). | Insignificant (assumed) |

The environmental impacts relating to the production of capital goods utilised in the aquaculture and fisheries life cycles, any human energy inputs, and the transportation of employees to and from their normal place of work were excluded from the assessment. As the majority of production site/landing port (including storage etc.) premises were built over 20 years ago, no emissions from land use change are included in this study.

Recent research (Sala *et al.*, 2021) has identified the potentially significant impact of the release of stored carbon by fishing gears that disturb the seabed. The understanding of this impact, and how it varies between gears and benthic habitats, is limited and so it is difficult to quantify the extent of carbon release for inclusion in an LCA. Ruiz-Salmon *et al.*, (2021) found that seafood LCA methodologies did not include this impact, despite recent proposals by Woods & Verones (2019). The seafood-specific standard, PAS 2050-2, does not include this impact and therefore the methodology adopted for these LCAs does not include release of carbon from the seabed by fisheries using bottom-contacting gear within the calculation of carbon emissions.

## Life Cycle Inventory

This study collected primary Life Cycle Inventory (LCI) data from active parties in the Irish Seafood supply chain, the details of the data collection are included within supplementary datasheets. This data is believed to reflect the normal operating conditions of the Irish Seafood sector and therefore is considered to be representative. An assessment period of three years was applied to both the capture fisheries and aquaculture systems (PAS 2050-2). Data was collected between 2017 and 2019.

All background data was sourced from Ecoinvent v3.7.1 (2020), As per the requirements of PAS 2050. The environmental impact categories chosen for this assessment are only Global Warming Potential (GWP) in line with the project scope.

The system boundary provides for a single fishing unit process to cover most of the activity. However, the boundary includes all activities to the transfer of the catch to processing or sale and must then include transport on land to home port facilities where this takes place. Thus, a second unit process has been added. No modelling is required to account for transfers between Unit Processes.

## Data gathering

The key data gathered included:

- Fuel use by boats and harvest equipment.
- Oils and coatings used on boats and harvest. equipment.
- Materials to repair gear.
- Refrigerants.
- Potable water.
- Packaging.
- Fuel use by vehicles transporting catch to home port.

## Greenhouse Gas Emissions Calculation Methodology

The calculation of the greenhouse gas emissions associated with the Irish fishing fleet was focused solely on the vessel's consumption of marine diesel. This was driven by the Life-Cycle Assessment (LCA) findings of the project's *Nephrops* LCA which identified >97% of global warming potential impact was related to marine diesel consumption. This finding was supplemented by the project literature review also highlighting similar emissions breakdown associated with marine diesel consumption.

The available data for Irish fishing vessels from the DCF datasets was only energy costs (€) which was assumed to relate to marine diesel costs only. This monetary value was converted to a marine diesel litres value by dividing it by an average €/litre average cost for the calendar year the costs were attributed to i.e., 2017, 2018 and/or 2019.

The marine diesel consumption (litres) value related to each sampled Irish fishing vessel was converted to a greenhouse gas emission ($CO_2e$) value by multiplying the fuel litres consumption value by a secondary greenhouse gas emissions factor (UK Government Conversion Factors for Company Reporting 2017, 2018, 2019 - 'marine gas oil' emission factor) in line with The Greenhouse Gas Protocol methodology.

The conversion factors include emissions associated with combustion of marine diesel fuel in the vessel only therefore excludes upstream emissions associated with marine diesel extraction, production and transportation.

An example calculation is provided below for a vessel's emissions across 2017-2019 within the Prawn and Whitefish 18-24m segment.

The DCF data included additional anonymised vessel specific data which was used to analyse the fleet emissions. As well as annual marine diesel costs, this also included annual tonnes fish landed, days at sea, days fishing, age of vessel, engine size (kW).

Absolute greenhouse gas emissions per vessel in 2017, 2018 and/or 2019 (as available) was normalised against the recorded tonnes fish landed value from the DCF dataset across 2017, 2018 and/or 2019 (as available). This analysis enabled a review of the differing greenhouse gas emissions/tonne fish landed across active vessels per specific vessel segment providing an average value per vessel segment.

Influencing factors on this greenhouse gas emissions/tonne fish landed value per segment were reviewed against available values within the DCF dataset such as kW rating of engine, days at sea, days fishing and age of vessel. In addition feedback from vessel skippers was sought to contextualise fuel efficiency and emissions further.

## Sample Size

In total 336 Irish fishing vessels were sampled across 2017-2019 from an average of 1,984 vessels (2017-2019), a sampling rate of 16.9%. This sample was directly influenced by data available from the DCF. Not every vessel listed included marine diesel costs or tonnes fish landed and where data was absent for a single vessel for either energy costs or tonnes fish landed this vessel was not included within the sample. The 1,984 vessels exclude aquaculture vessels as this fleet segment is not sampled under the DCF. The sample size is represented below, split according to segment type and ordered by the percentage of vessels covered from the segment compared with total vessels in the segment.

**Table 5:** Example Emissions Calculation.

| Year | Carbon Segment | Tonnes landed | Annual Vessel Fuel Cost | Litres | tCO2e | tCO2e/tonne fish landed |
|---|---|---|---|---|---|---|
| 2017 | Prawns and Whitefish 18-24m | 374.10 | €298,403 | 732,876.8 | 2,008.1 | 5.37 |
| 2018 | Prawns and Whitefish 18-24m | 240.78 | €352,503 | 588,387.6 | 1,632.7 | 6.78 |
| 2019 | Prawns and Whitefish 18-24m | 347.30 | €306,547 | 630,960.7 | 1,751.2 | 5.04 |

**Table 6:** Sample values for each segment of the Irish fishing fleet.

| Vessel Segment | Sample Count (entries covering 2017-2019) | Number of vessels represented by at least one year (2017-2019) | % of vessels covered from segment compared with total vessels in segment |
|---|---|---|---|
| Hake Gillnetters | 12 | 9 | 96% |
| Prawns and Whitefish 24-40m Trawlers | 19 | 10 | 64% |
| RSW Pelagic | 21 | 13 | 57% |
| Seiners | 9 | 5 | 56% |
| Beamer | 17 | 8 | 56% |
| Freezer Trawlers | 41 | 28 | 46% |
| Prawns and Whitefish 18-24m Trawlers | 22 | 14 | 43% |
| Prawns and Whitefish 12-18m Trawlers | 23 | 15 | 35% |
| Other* | 182 | 128 | 14% |
| Potter 0-1a | 149 | 106 | 13% |

*vessels labelled as 'other' in the data are those not classified against a specific segment.

# Notes

# Notes