**Methods**

Multiple sources of data, including [*life cycle assessments*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self) (LCAs), fuel use datasets, industry and government reports, and direct communication with experts, were used to calculate the [*carbon footprints*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self) presented in the Seafood Carbon Emissions Tool. The tool includes carbon footprint estimates for 154 seafood products: 101 for fisheries and 53 for aquaculture.

The carbon emission estimates presented in the tool are specific to the species and the production methods (i.e. fishing gear type or aquaculture farm type), are calculated up to the dock or farm gate (the point of departure of a seafood product from primary production and before processing) only and presented as per kg of weight of fish or shellfish, and as per kg of protein from fish or shellfish, using species-specific flesh yields and nutritional values. The carbon emission estimates can be viewed per species or as aggregated averages per group of species.

For [*fisheries*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)[,](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)) the data inputs used to calculate carbon footprints include the amount of fuel consumed by fishing vessels and, if applicable, the amount of bait used in fishing operations, with corrections made to account for other emissions sources. For [*aquaculture*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self), data inputs include the amount and types of feed used in operations and the amount and source of energy required to power the farm facilities. The methods that use these data inputs to model fisheries and aquaculture production operations are described in more detail below. References to some key studies are provided in the more info section of the data card profiles for each species.

**Fisheries**

Estimates of carbon emissions from wild-capture fisheries production were based largely on rates of fuel consumption. Burning of diesel by fishing vessels typically accounts for between 60 % to 90 % of the [*greenhouse gas*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)(GHG) emissions of a fishery product up to the point of landing1. Data used to calculate fishery carbon emissions were extracted from a Fisheries Energy Use Database (FEUD) compiled and managed by Dr. Rob Parker (University of British Columbia) and Dr. Peter Tyedmers (Dalhousie University). This database includes data from government and industry reports, direct communications with industry experts and peer-reviewed literature2-3.

If possible, fuel use records specific to the target species and gear (and in some cases fishing country) were used to calculate each carbon footprint. In cases where some data were lacking, inferences were made using data from fisheries with similar characteristics. For example, if data were not available for the Pacific halibut longline fishery, but data were available for other longline fisheries for flatfishes, then an estimate was calculated using fuel use rates observed in these comparable fisheries. Where estimates were based on comparable fisheries rather than direct data, this limitation was highlighted in the fishery notes. After appropriate fuel use records were selected, the 25th and 75th percentiles were used to provide a range of expected fuel use rates for the fishery, in liters of fuel per tonne of whole, unprocessed fish. For estimates that were based on a single data point, a range around that data point was estimated based on similar fisheries.

Fuel use values were multiplied by an emissions factor of 3.3 kg CO2-eq per liter, which includes both emissions from burning the fuel as well as emissions from upstream processes of the mining, refining, and transportation of the fuel2. The resulting quantity of emissions was further multiplied by 1.33 to account for emission sources for which input data are scarcely available but can contribute significantly to the overall carbon footprint. These sources include the loss of refrigerants and emissions associated with vessel and gear maintenance and manufacture. Overall, these calculations reflect a rough estimate of fuel use accounting for 75% of pre-landing GHG emissions. Finally, emissions estimates were added for fisheries requiring bait (*e.g.*tuna longlines, lobster traps,*etc.*) using data collected from literature, Seafood Watch reports, and online searches. Ranges of emissions associated with bait use were established for each fishery category: 0-5% of landed weight for tuna fisheries, 5-40% for whitefish fisheries, 40-60% for crab trap fisheries, and 100-300% for lobster trap fisheries.

Each fuel use estimate in FEUD comes from different data source types, are from different years, have different sample sizes and are estimated using different methods. To help understand this variation in data, certainty scores were produced for each carbon footprint estimate. These scores reflect the degree to which each estimate is expected to reflect reality, based on the following criteria:

* the availability of FEUD records matching the species and gear
* the total number of data points available
* the number of unique sources reporting data
* the age of each data point
* the variance observed across all of the data points included in an estimate

It is useful to note that a carbon footprint estimate for a fishery that uses numerous, consistent fuel use records that have been reported by multiple sources over the past decade would produce a carbon footprint estimate with a high degree of certainty. Conversely, estimates for fisheries with no species-specific data, data from a single data source or data from more than 10 years ago would produce a carbon footprint estimate with a low degree of certainty.

**Aquaculture**

LCAs have consistently identified feed and energy use as the primary sources of GHG emissions in aquaculture operations. Feed dominates emissions produced from marine net pen and floating cage systems4-5. In land-based operations, large amounts of energy are often required to provide services that would otherwise be provided by the natural environment, such as temperature control and oxygen regulation6-7. In such cases, knowing the source of electricity used—whether from renewable sources, nuclear energy, or fossil fuels—is critical in determining emission estimates.

Carbon footprint estimates for aquaculture production systems were constructed using Monte Carlo simulations (repeated sampling of datasets with estimated distributions) with five input parameters. These parameters were:

* the [*economic feed conversion ratios*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self) (eFCR) of the species (kg of feed required to produce 1 kg of fish)
* the relative amount of feed coming from fishery, crop, and poultry by-product sources (mammal by-products were not considered here as their use in [*aquafeeds*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)is uncommon)
* the reported GHG emissions associated with the different feed inputs used in aquaculture operations
* the rates of total on-farm energy use, including both [*hatchery*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)[/](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a))juvenile production and [*grow-out*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)
* the amount of on-farm energy derived from diesel, petrol/gasoline, and electricity

Data to support the mean and standard deviation estimates for each of the 5 parameters were gathered from published LCAs, Seafood Watch reports, life cycle inventory databases, government and industry reports, and through communications with industry experts.

Emissions from electricity production were estimated for each country producing a notable amount of the species being assessed. The emissions associated with these country electricity grids were based on the production of renewable and non-renewable energy sources derived from the [ecoinvent 3.0 database](http://www.ecoinvent.org/database/older-versions/ecoinvent-30/ecoinvent-30.html).

After running simulations (each of 10,000 iterations) using the above parameters for each carbon footprint estimate, the 25th and 75th percentiles were selected as the upper and lower limits of each emission estimate.

Similar to fisheries, the availability of data relevant to aquaculture production varies between species and production operations. Some species and operation types have been studied extensively, such as Atlantic salmon in marine net pens while others have much less data available, such as the amount of energy required for the land-based production of whitefish species. The variation within the data reported for less commonly studied species is also often higher than for commonly studied species. To illustrate the differences in certainty inherent with these data availability and variation issues, certainty scores were produced for each carbon footprint estimate similar to those for the fisheries operations, based on the following criteria:

* the number of data points for each parameter
* the number of unique sources providing data points
* the variation within the available data
* the consistency of data used for similar species and production systems

While the methods used to estimate carbon footprints were consistent across seafood production operations, for some there are additional sources of emissions that are not currently included in the Seafood Carbon Emissions Tool due to a lack of data. For example, data on indirect land-use change emissions for coastal farming of shrimp, and methane emissions from ponds and rice paddies are uncommon and associated with a great deal of uncertainty8. The estimates displayed in the Seafood Carbon Emissions Tool therefore only reflect emissions associated with feed and energy, but future updates to the tool with new data may allow integration of some of these additional sources of emissions.

**Comparisons to other animal protein sources**

The Seafood Carbon Emissions Tool also includes estimated carbon footprints for the terrestrial-based proteins; soy, chicken, pork, beef and lamb. These were derived by reviewing LCAs for these production systems. A total of 53 studies detailing the life cycle emissions from terrestrial protein production systems up to the farm-gate were used to calculate the carbon footprints for these terrestrial proteins. The emission sources in each study varied, but typically included the use of electricity and fuels, feed production, fertilizer production and use, and methane emissions from [*ruminant*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self) digestion and [*manure management*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self). Efforts were made to exclude studies which assessed hypothetical, experimental, or otherwise non-representative systems.

In the current version of the Seafood Carbon Emissions Tool, land transformation of farm sites, which can be significant (particularly for soy), is not accounted for in estimates of carbon footprints. Studies assessing the effect of [*land use change*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self)for terrestrial proteins were therefore excluded from the calculation of carbon footprints. The studies used still varied in their scope, methods, data sources and assumptions. The ranges for terrestrial protein production in the Seafood Carbon Emissions Tool are therefore intended to be broadly representative of each protein type and not necessarily applicable to any individual farm or product.

A total of 81 data points were gathered from the 53 studies reviewed (6 for soy, 13 for chicken, 23 for pork, 27 for beef and 12 for lamb). GHG emission values were converted to units of carbon dioxide equivalent (CO2-eq) per kg of protein based on ratios of live weight and [*carcass weight*](http://seafoodco2.dal.ca/(overlay:menu/5bcb5081add43f22b2c6f12a)/?self) to meat yield and protein content, following the approach of Nijdam and colleagues9. From the resulting range of emissions for each system type, the 25th and 75th percentiles were selected as the upper and lower limits for carbon estimates to display in the Seafood Carbon Emissions Tool. These were expected to capture the typical emission values for each system.

Chart

Description automatically generated with medium confidence

**GHG emissions from terrestrial protein sources.** Boxes show the median value and 25th and 75th percentiles from the LCA studies reviewed. Extended lines show the maximum and minimum values from studies.

**Emissions from transport**

In many cases, transport contributes negligibly to the carbon footprint of seafood products10. There are, however, exceptions. Air transportation of some products, such as live lobster or some fresh fish products, can increase emissions dramatically11. The [transport calculator](http://seafoodco2.dal.ca/(overlay:menu/transport-calculator)) can be used to estimate the carbon footprint associated with the transport of a seafood product from its origin to its final destination for multiple transport modes. The values used to quantify transport-related emissions were averaged from data extracted from the [ecoinvent 3.0 database](http://www.ecoinvent.org/database/older-versions/ecoinvent-30/ecoinvent-30.html) from the Swiss Centre for Life Cycle Inventories12 as well as the [Agri-footprint database](http://www.agri-footprint.com/) from Blonk Consultants13. Average emission estimates in kg CO2-eq per tonne-kilometer included: 0.02 for ocean freighter, 0.03 for rail, 0.33 for truck, and 0.95 for plane.

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