Estimating the Carbon Footprint of Tuna Fisheries

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SUMMARY

This report gives the findings of a study commissioned by WWF to estimate the carbon footprint of tuna fisheries. Carbon footprint, which indicates the carbon dioxide emissions generated by a product system or supply chain per unit of output on a life cycle basis, provides a quantitative index of potential adverse impacts with respect to climate change. The carbon footprint can be computed using extended Leontief input-output models based on “top-down” or “bottom-up” data. Initial attempts using top-down data appear to underestimate the total carbon footprint. The initial estimates were revised using activity- and process-based (“bottom-up”) data for different types of fishing gear, as well as various alternative scenarios for downstream processing and logistics. One of the main findings is that fishery fleet fuel consumption is typically the largest contributor to overall carbon footprint. Purse seine fishing gives the lowest carbon footprint per kg of landed catch, while long line gear has the largest footprint. Furthermore, the footprint figures are highly sensitive to yields, which then implies that carbon footprint reduction is compatible with increasing fishery profitability. The other major contributors to the overall carbon footprint are cannery operations and transportation by air. Cold storage, on the other hand, has a relatively minor contribution.

INTRODUCTION

Discussions pertaining to the sustainability of commercial fisheries have traditionally focused on the issue of optimal exploitation of stocks relative to their regeneration capacity. More recently, concerns have been extended to other environmental aspects of fisheries and seafood product systems. In particular, policy-makers and the general public have come to recognize climate change as perhaps the single most critical environmental issue in the world today. Although much of the 25×10^9 tons of carbon dioxide generated each year globally results from land-based industrial activity and energy use, Thrane et al. (2009) now list it as one of the major issues facing commercial fisheries:

- Overexploitation of target species
- Indirect impacts on non-target species as by-catch or via food chain disruption
- Direct wastes from fishing activities
- Carbon emissions from related activities
- Indirect impacts from downstream product chain

Thrane et al. (2009) have compared efforts to provide environmentally conscious consumers with relevant information on the sustainability of specific seafood products through various eco-labels such as the MSC (Marine Stewardship Council) Label, the Swedish KRAV Label and the DSLS (Danish Society for a Living Sea) Label. They concluded that most of the eco-labels tend to overemphasize impacts arising directly from fisheries, rather than providing a more balanced perspective of the impacts arising from the entire product chain. Figure 1 illustrates how product systems affect the environment through various routes. It is notable that some emissions and impacts occur outside the marine environment, but that secondary effects may become manifested through an indirect pathway. This is particularly true in the case of emissions of carbon dioxide and other greenhouse gases (such as methane or nitrous oxide), which may be generated at various points within the product life cycle; even though these emissions are released into the atmosphere and the principal effects are felt in the form of climate change, the latter may then causes changes in marine ecosystems which then further compromise the sustainability of commercial fisheries. As stocks of the commercially valuable fish species thin out, the amount of energy expended (and the corresponding greenhouse gas emissions) for a given level of catch may then increase, leading to the vicious cycle illustrated in Figure 2.

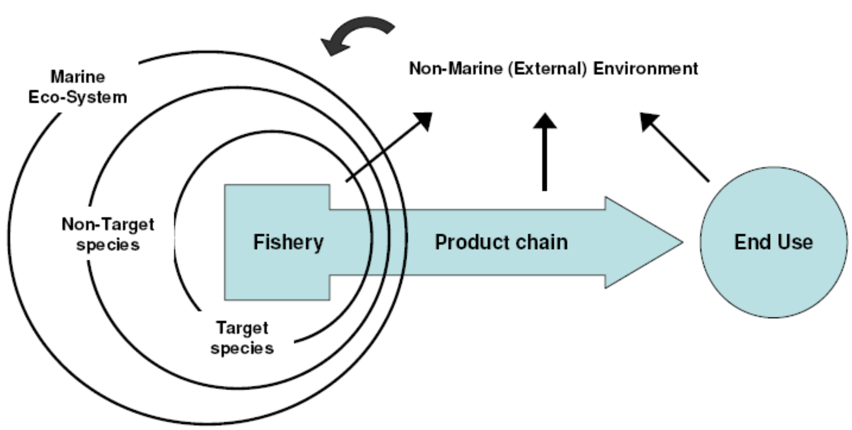

Figure 1. Interactions of the seafood product system with the environment (Thrane et al., 2009)

The overall carbon emissions of a supply chain has recently come to be known as “carbon footprint.” Estimation of this footprint is similar to a simplified form of life cycle analysis. It provides a single numerical index of environmental performance which is easily understandable; however, the carbon footprint concept may be criticized as being one-dimensional, as it focuses on climate change effects while completely excluding all other environmental aspects of a product (Weidema et al., 2008). This study was commissioned by WWF as part of an effort to estimate the contribution of tuna fisheries to climate change, by determining their typical carbon footprints.

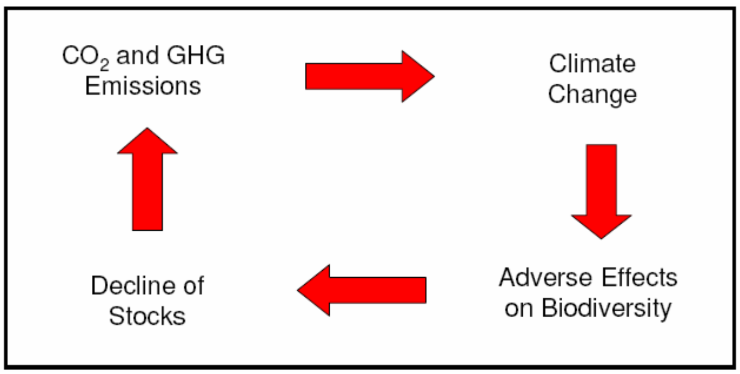

Figure 2. Climate change as part of a vicious cycle for commercial fisheries

SCOPE AND LIMITATIONS OF THE STUDY

This study focuses on the estimation of the carbon footprint of tuna fisheries through input-output modeling. The carbon footprint is estimated on the basis of each kg of catch, and accounts for contributions from direct and indirect fuel combustion to support fleet activities. It also includes downstream emissions from processing, storage and transportation. The initial estimate was computed on the basis of top-down data from the input-output tables of the Philippine economy. A second, more refined estimate was derived from actual fleet data from a company whose identity is withheld for confidentiality. This data is used to revise estimates of the direct portion of the carbon footprint of tuna fisheries. Energy use in downstream processing and handling of the tuna were based on values reported in literature. However, this study estimates on carbon dioxide emissions, and does not include the contributions of other greenhouse gases generated within the supply chain.

METHODOLOGY

The modeling approach used to estimate the carbon footprint of tuna fisheries is input-output analysis (IOA). IOA was originally developed by Leontief to analyze industry linkages, but it has since been extended to applications involving computation of levels of pollutants generated by life cycle systems comprised of interconnected processes and activities (Heijungs and Suh, 2002; Hendrickson et al., 2006). The approach is also suitable for the special case of computing a single overall footprint or environmental indicator (Turner et al., 2007). In the case of climate change, the key indicator is the so-called carbon footprint, which quantifies the amount of carbon dioxide generated directly and indirectly by the entire life cycle, per unit of specified output.

The basic model for using IOA to estimate carbon footprint is:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{y} \tag{1}$$

$$g = \mathbf{b}^{\mathrm{T}}\mathbf{x} \tag{2}$$

Where $\mathbf{y}$ is the final output vector; $\mathbf{x}$ is the gross output vector; $\mathbf{I}$ is an identity matrix; $\mathbf{A}$ is the technology matrix characterizing the interconnections among sectors or processes existing within the product system; $\mathbf{b}$ is the vector of direct carbon intensities of the sectors or processes represented in $\mathbf{A}$; and g is the carbon footprint per unit of final output $\mathbf{y}$.

Note that $\mathbf{A}$ reflects the relative yields of the sectors and processes that make up the system; this matrix as well as $\mathbf{b}$ are primarily functions of the state of technology. Furthermore, the flow of goods in $\mathbf{A}$ can be given in physical terms (e.g., kWh or MJ for energy flows and kg or tons for material flows) or in terms of economic value. The values of the parameters of $\mathbf{A}$ and $\mathbf{b}$ may be estimated using three approaches:

- Top-down estimation derived from national or regional IO tables
- Bottom-up approaches derived from process-level or firm-level data
- Hybrid approaches combining data from the above

Top-down approaches offer the advantage of reflecting essentially complete inter-industry linkages, at the expense of low resolution or differentiation between products from the same sector (e.g., different types of seafood from commercial fisheries). At the same time, it should be noted that national accounts as reflected in IO tables are inherently historical in nature, and errors in estimation may arise as a result of the time lags. On the other hand, process data from bottom-up approaches may suffer from completeness, and may not be fully representative of industry averages (Hendrickson et al., 2006).

KEY FINDINGS

An initial estimate of the carbon footprint per kg of tuna was computed based on a top-down, 60-sector IO model of the Philippine economy in the year 2000, developed at CESDR in De La Salle University. The carbon footprint at the wholesale gate is estimated at 0.25 – 0.30 kg per kg of tuna, of which about half comes directly from fishing fleet operations. Contributions of various activities to the total are shown in Figure 3.

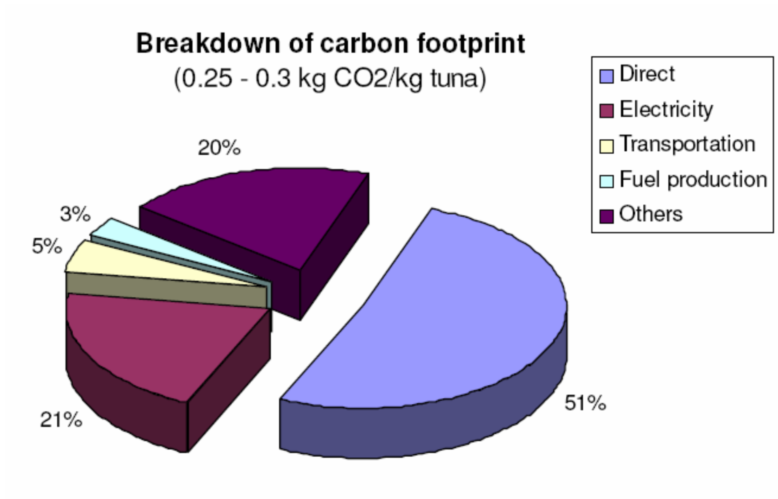

Figure 3. Top-down estimate of the carbon footprint of 1 kg of fresh tuna at the wholesale gate

The corresponding carbon footprint estimate for tuna at the retail level in Manila is about 0.80 – 0.90 kg per kg. The additional carbon footprint is incurred during handling, storage and transport of the fish. By comparison, estimates of the carbon footprints of each kg of other protein sources and staple foods are: 1.43 – 1.75 kg for beef; 1.27 – 1.35 kg for pork; 1.42 kg for poultry; and 0.23 kg for rice. It should be noted that these footprint values do not reflect the additional equivalent climate change impacts of the sizeable methane emissions generated in the production of these other food sources.

The main drawbacks of these estimates are inherent to the top-down approach. First, the IO model was developed from the most recent available data of the national accounts of the Philippines, which date back to the year 2000. Secondly, all commercial fisheries are lumped together within the same sector inside the model. The implicit assumption of the top-down approach is that any technological differences among products coming from the same sector (i.e., different types of fish) are reflected in their price or cost. In this sense, the top-down approach does not fully differentiate between different goods from the same sector of the economy.

A second estimate was then computed using the bottom-up, activity- or process-based approach. In this phase, the major modifications are as follows:

- Comparative analysis of different types of fishing gear (purse seine, long line and pump boats)

- Inclusion of the footprint of downstream activities (cold storage, cooking and canning, transport by land, sea or air)

- Sensitivity analysis to account for variations in yields, and to identify promising opportunities for reduction of carbon footprint.

The key assumptions and partial results for the main fishing gear and downstream processes are described in the succeeding subsections.

Purse Seine

Estimation of the carbon footprint of tuna caught using purse seine gear is based on fuel usage data in the literature. Hospido and Tyedmers (2005) reported an average fuel consumption of 0.44 l/kg for nine Spanish vessels targeting Skipjack and Yellowfin tuna. The average diesel fuel consumption figures were 0.37 l/kg in the Indian Ocean, 0.44 l/kg in the Atlantic and 0.53 l/kg in the Pacific. The figure computed from the data provided by a locally-based firm was 0.60 l/kg, which is in close agreement with the values from literature. This figure includes energy consumption for auxiliary equipment, particularly refrigeration. Nevertheless, there is significant variance depending on fleet yields. For instance, an earlier study reports a fuel consumption figure of 1.7 l/kg, which is three to four times larger than these estimates. A carbon emissions factor of 3.1 kg CO_2 per liter of diesel is assumed, based on the GREET life cycle analysis model (Wang, 1999); note that this figure includes upstream emissions from the production and distribution of the fuel, in addition to the direct footprint generated during combustion. Based on these figures, the resulting partial footprint is 1.15 – 5.27 kg CO_2/kg of landed tuna.

Long Line

The carbon footprint of tuna caught using long line gear is based on the assumption a 1000 hp diesel-powered vessel equipped with 1000 hooks and with an average catch rate of 0.4 fish per 100 hooks per set. The fuel consumption is estimated at 0.06 l/hp-h, based on data provided by a local company. On the average the fish caught weigh 30 – 40 kg per piece, and it is further assumed that it takes an average of 4 h to set the line. Overall utilization of vessel running time is taken initially as 0.7 (i.e., the vessel is assumed to be actively fishing for 70% of its total running time). The emission factor of diesel fuel is still assumed to be 3.1 kg CO_2 per liter (Wang, 1999). Based on these figures, the resulting partial footprint is 6.64 – 8.86 kg CO_2/kg landed tuna.

Large Pump Boats

The carbon footprint estimate for large pump boats assumes 300 hp gasoline or diesel-fueled vessels operating for an average of 12 h per day over the course of a typical trip lasting 10 – 15 days. Each main vessel is supported by 10 – 12 small, 5 hp gasoline-powered vessels. Fuel consumption figures are estimated at 0.1 l/hp-h for gasoline boats and 0.06 l/hp-h for diesel-powered ones. Typical catch rate per trip is about 4000 kg. The emission factor of diesel and gasoline are assumed to be 3.1 and 2.9 kg CO_2 per liter, subject to the same assumptions described in the previous scenarios (Wang, 1999). From these figures, the partial footprint is estimated at 2.11 – 4.70 kg CO_2/kg landed tuna.

Small Pump Boats

In this scenario, it is assumed that the typical vessel is a 30 hp gasoline-powered pump boat making 6 trips per week, with each trip lasting about 5 hours. The weekly catch is estimated at 60 – 80 kg. As in the previous scenarios, gasoline consumption is assumed to be 0.1 l/hp-h and the emission factor of gasoline is taken as 2.9 kg CO_2/l (Wang, 1999). From these figures, the partial footprint is estimated at 3.26 – 4.35 kg CO_2/kg landed tuna.

Cold Storage

Typical well-operated cold storage facilities consume 30 – 50 kWh per m^3-y (Duiven and Binard, 2002). This range corresponds to 0.0025 – 0.0042 kWh/kg per month. In practice, there is a wide degree of variability depending on climatic conditions, maintenance practices and facility size. An undated report by Carlsson-Kanyama and Faist give much higher figures, ranging from 0.008

kWh/kg-month for large cold storage facilities to in excess of 0.12 kWh/kg-month for smaller freezers such as those in retail outlets. The emission factor of electricity is based on the average Philippine grid power mix reported by the Department of Energy (www.doe.gov.ph), and was calculated to be 0.5 kg CO_2/kWh using the GREET model (Wang, 1999). If an on-site diesel generator is used, the carbon footprint factor is 0.8 kg CO_2/kWh. Thus, for an average storage residence time of 60 days, the partial footprint is calculated to be 0.0025 – 0.013 kg CO_2/kg for large cold storage facilities, and 0.12 kg CO_2/kg for frozen storage at the retail level.

Cooking and Canning

The carbon footprint of tuna canning operations is based on electricity and heat consumption reported by Hospido et al. (2006). According to their study, 357 MJ of heat and 218.8 kWh of electricity are needed per 1000 kg of fresh tuna input. The bulk of the heat requirement is for thawing, cooking and retorting operations. They report a process yield of 0.66 kg of canned tuna (net weight) per kg of input. However, this figure maybe much lower for smaller sized fish. The yield here is assumed to be in the range of 0.35 – 0.65 to account for variations in fish size. Furthermore, as the remainder of the tuna not canned is processed further into fish meal, two allocation scenarios are considered. In the first case, the total energy consumption of the canning plant is allocated only to the canned product. In the second case, energy use is allocated on a weight basis, so that a portion of the resulting carbon footprint becomes attributed to the fish meal byproduct. Based on the average Philippine grid power mix reported by the Department of Energy (www.doe.gov.ph), the emission factor for electricity was calculated to be 0.5 kg CO_2/kWh using the GREET model (Wang, 1999). For process heat, the factor is 0.086 kg CO_2/MJ using either diesel or bunker fuel; on-site electricity production using a diesel generator is assumed to give a carbon footprint of 0.8 kg CO_2/kWh. Based on these assumptions, the partial carbon footprint is estimated at 0.63 – 1.38 kg CO_2 per kg of product, if all of the energy consumption is allocated to the canned tuna. If part of the energy use is allocated on a weight basis to the fish meal byproduct, the partial footprint is only 0.42 – 0.48 kg CO_2 per kg. Note that these estimates exclude the footprint contributed by the packaging material.

Transportation

The carbon footprint factors used are 0.50, 0.105 and 0.025 kg CO_2/kg-10^3 km for air, land (road) and maritime freight, respectively. These values are based on those used by the footprint calculator of Carbon Fund (www.carbonfund.org). it is assumed that the total transport over the entire supply chain is 3000 kg by air or by sea, plus and additional 300 km by land. The resulting footprint is thus 1.53 kg CO_2/km using air freight and 0.11 kg CO_2/km using maritime freight. Note that these figures represent a difference of one order of magnitude between the two transport modes over the same total distance.

Summary of Partial Footprints

Table 1 gives the summary of partial carbon footprint results from the previous subsections. Note that the magnitude of the figures for fishing are ,in general, much larger than the other activities. The footprint contributed by cooking and canning and transportation (using the assumed scenarios) are of comparable magnitude, while that of refrigeration and cold storage is significantly smaller.

Table 1. Partial Footprints of Key Processes and Activities

Process/Activity	Carbon footprint (kg CO_2/kg)
Fishing (Purse Seine)	1.15 – 5.27
Fishing (Long Line)	6.64 – 8.86
Fishing (Large Pump Boat)	2.11 – 4.70
Fishing (Small Pump Boat)	3.26 – 4.25
Cold Storage	0.0025 – 0.12
Cooking and Canning	0.42 – 1.38
Transportation (Cumulative)	0.11 – 1.53

Total Footprints for Different Supply Chain Options

The partial footprints in Table 1 can be combined to calculate the total carbon footprints for different supply chain options using Equations 1 and 2. It is essential that uncertainties in the data be reflected properly by calculating both high and low estimates for the carbon footprint figures. The results for frozen and canned tuna are given in Figures 3 and 4, respectively. In both cases, it is clear that long line fishing has markedly higher footprint than the three other fishing techniques, even when data variability is taken into account.

It can also be seen from these results that the footprint for canned tuna is much higher than that of frozen tuna. There are two reasons for this. Firstly, the results in Figure 4 also include the carbon footprint contributed by energy use during canning and cooking. It can be noted from Table 1 that this contribution is fairly large in comparison to energy use for storage. Secondly, the high end estimates for canned tuna reflect process losses (at recovery levels of 35%) under the assumption that the entire carbon footprint is attributed to the canned product, and none at all to the fish meal byproduct made from the scraps. It should also be noted that the frozen tuna may incur additional carbon footprint as a result of domestic cooking by the consumer, unless it is consumed raw. Thus, direct comparison of the data in Figures 3 and 4 is not really possible without making further assumptions.

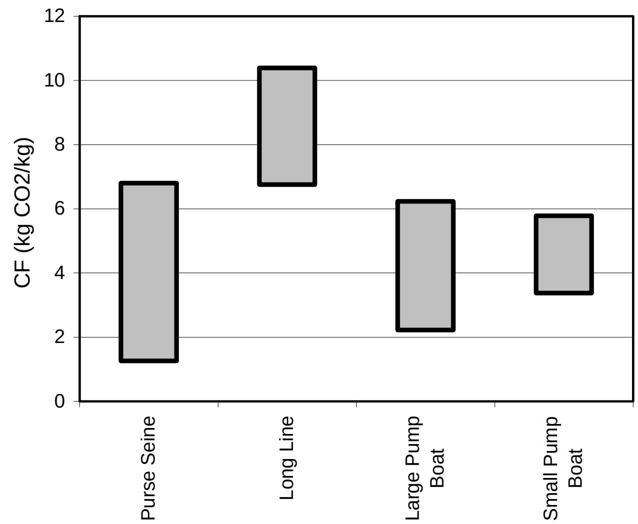

Figure 3. Carbon Footprint of Frozen Tuna

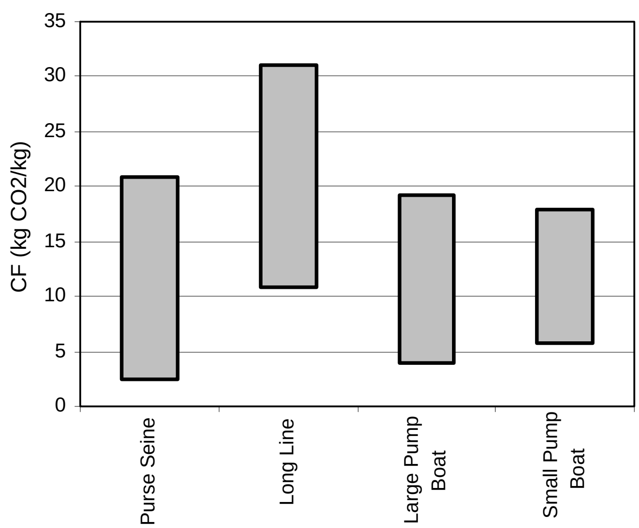

Figure 4. Carbon Footprint of Canned Tuna

Figures 5 and 6 show the contributions of four major activities (fishing, cooking/caning, cold storage and cumulative transportation) to the carbon footprint of each kilogram of tuna delivered to the consumer. Figure 5 is based on the optimistic assumptions with the highest yields and lowest energy consumption levels. Note that direct carbon emissions from fishing dominate the totals reflected in these results. In the case of canned tuna, the second largest contributor are the cooking and canning process. The contribution of transportation is small due since this assumes delivery of the tuna by sea, with a correspondingly low carbon footprint.

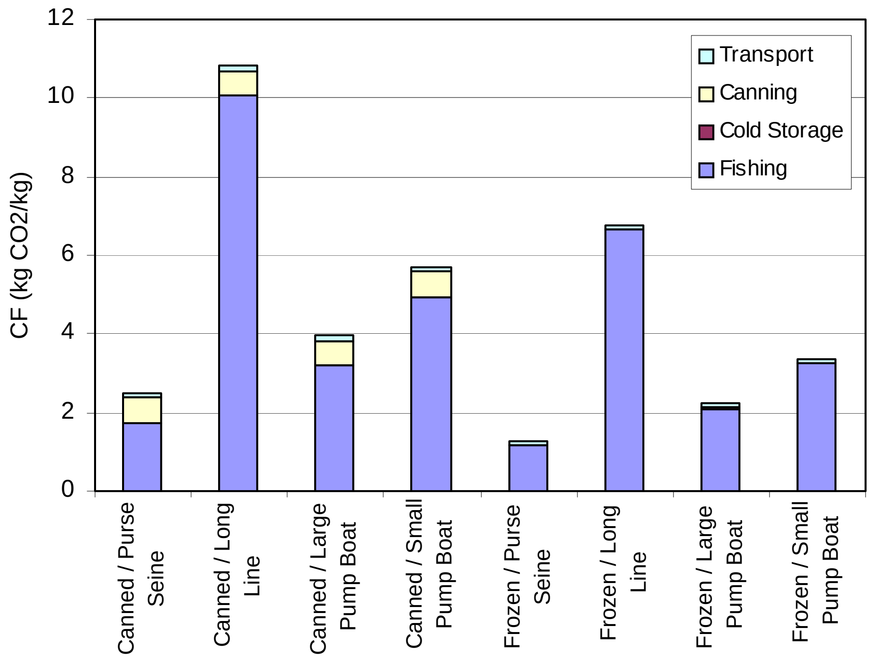

Figure 5. Contribution Analysis for Optimistic Scenario

Figure 6 shows the results for the more conservative case, in which low yields and high energy consumption are assumed. Furthermore, in this scenario it is assumed that the tuna is transported via air freight, which results in a marked increase in the contribution of transportation across all cases. Direct emissions from fishing activities are still the dominant contributor. For canned fish, cannery operations account for the second largest contribution, followed by transportation throughout the supply chain. In the case of frozen fish, transportation is the second largest contributor. The footprint contribution of refrigeration is relatively small for all the cases evaluated.

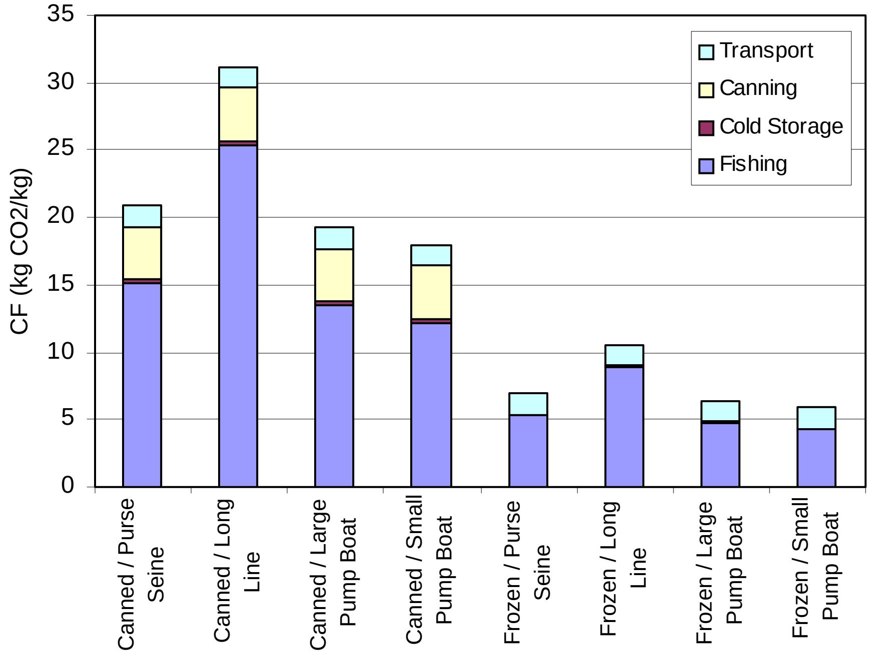

Figure 6. Contribution Analysis for Conservative Scenario

Discussion of Main Implications

It is possible to draw some important conclusions from the process-based evaluation of the carbon footprint of tuna. The main findings are summarized as follows:

- For all scenarios considered, direct carbon emissions from fuel combustion during fishing operations are the largest contributor to the total carbon footprint. Long line fishing was also found to have markedly larger footprint than the other fishing methods evaluated. The magnitude of the footprint varies widely and is also highly dependent on yields, which has two main implications. On one hand, it indicates that the carbon footprint is highly sensitive to depletion of stocks, and that the average footprint may increase as fisheries consume more energy to maintain catch levels. On the other hand, it also indicates considerable potential for reduction of carbon footprint through technological improvements in fishing gear and methods.

- Cannery operations account for a sizeable fraction of the overall carbon footprint in the case of canned tuna. Furthermore, the cannery yield also influences the magnitude of upstream carbon emissions per unit of product. That is, if more fresh tuna is needed to make each unit of canned final product, there will be correspondingly larger emissions from fishing operations in order to supply the larger quantity of input required. Cannery yields tend to decrease as the average fish size decreases. This effect may thus create an undesirable feedback loop (See Figures 1 and 2) in which carbon emissions are further exacerbated by the decline in the quality of fish stocks.

- For the assumed 60-day average storage period, the carbon footprint contribution of refrigeration and cold storage is much smaller than any of the other major activities or processes evaluated in this study.

- The contribution of transportation to the overall carbon footprint depends strongly on the mode. Emissions from shipment by air are roughly an order of magnitude larger than corresponding emissions from maritime freight. If the tuna is transported using aircraft, the carbon footprint contribution for the average distance assumed in this study (3000 km) is comparable in magnitude to the emissions generated by cannery operations, and is significantly larger than any footprint that may be incurred by additional refrigeration expense due to longer transit times when the product is shipped by sea.

CONCLUSIONS

Input output modeling has been used to estimate the carbon footprint of commercial tuna fisheries. An initial estimate using top-down data was first made, but the figure was later adjusted in light of data provided by a commercial fishing fleet as well as from literature sources. The carbon footprint is dominated primarily by fuel combustion during fishing operations, both for fleet propulsion and powering of auxiliary on-board equipment. Considerable opportunities still exist for reducing the footprint through energy efficiency enhancement in downstream (post landing) product chain, particularly in canning, transportation and distribution. On the other hand, the footprint contribution of refrigerated storage is much smaller than those of all the other major activities in the tuna supply chain.

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