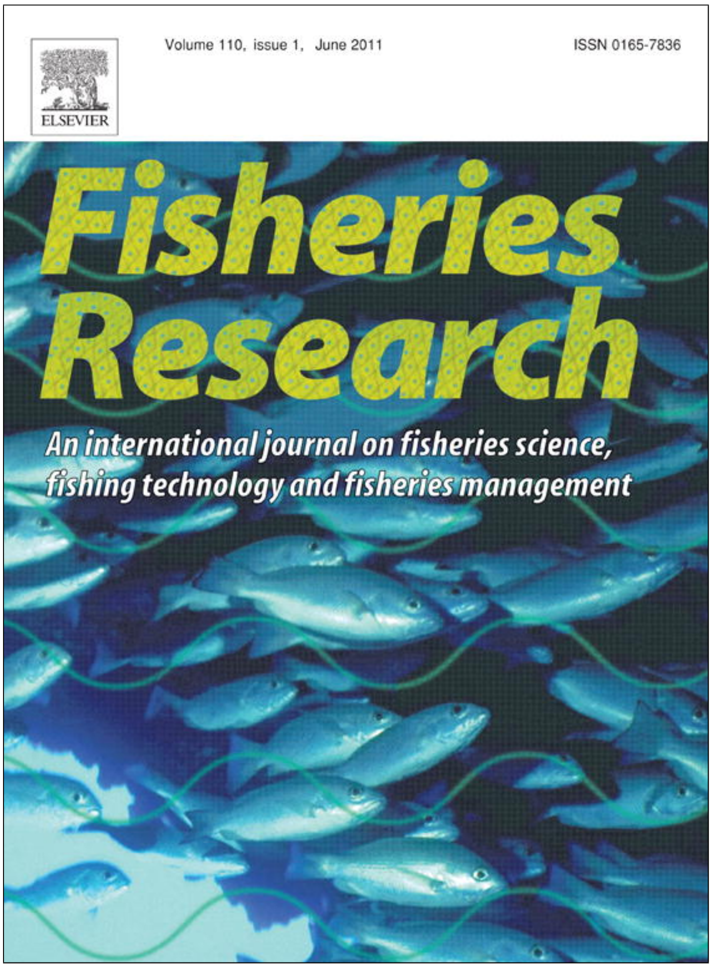
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Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock

Ian Vázquez-Rowe*, Mª Teresa Moreira, Gumersindo Feijoo

Department of Chemical Engineering, School of Engineering, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain

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ABSTRACT

European hake (*Merluccius merluccius* L.), one of the main products in the Spanish diet, represents the highest economic income for Galician fishing fleets. In this study, Life Cycle Assessment (LCA) was used to assess the environmental impacts related to the extraction, processing and consumption of European hake captured by Galician trawlers and long liners in the Northern Stock. Furthermore, biological related impact categories, such as by-catch and discards were also considered in the analysis. Results show considerably lower environmental impacts for European hake fresh fillets arriving from long lining vessels, due mainly to the high energy demand of the analyzed trawlers. In this sense, the main part of the impact for hake arriving from both fishing fleets was attributable to marine diesel-linked activities. Post-fishing activities, such as land transport or electricity consumption, were also highlighted as important contributors within their subsystems. Global environmental performance of the system can only be reduced through fuel consumption minimization. However, impact minimization in the fresh hake post-harvesting activities may offer attractive cost reductions for retailers, wholesalers and consumers.

1. Introduction

1.1. Hake fisheries

The hake family Merlucciidae has traditionally been a very important catch within the fishing industry, as many of its species sustain a significant fishery (FAO, 2005). This genus is highly distributed geographically, being present in both hemispheres and in all oceans. However, more than two-thirds of the worldwide hake catch is captured in Atlantic waters. This situation is related to the fact that hake is a very popular dish in some Ibero-American countries, especially Spain, Argentina and Uruguay, constituting an important protein source in the dietary habits of the population. In 2001, the average Spanish citizen consumed 16.3 kg of fresh fish annually, of which 3.3 kg corresponded to hake species (Piquero and López Losa, 2001). Therefore, it is not surprising that over 40% of the hake landed in European ports comes from a Galician port (Fig. 1).

European hake, *Merluccius merluccius* (Linnaeus 1758), is the main species found in the Northeast Atlantic ranging from Norway to the Gulf of Guinea, including the Mediterranean and Black seas (Casey and Pereiro, 1995). It is a large predatory fish found mainly in demersal areas on the continental shelf and upper continental slope. European hake is the most representative fish that the Spanish population eats fresh, arriving mainly from the so-called Northern Stock (ICES Divisions VIIIa, b, d and VII) and Southern Stock (ICES Division VIIIc and IXa).

It is estimated that hake fisheries nowadays show low possibilities for expansion, due mainly to overexploitation, despite the increased resistance to fishing pressure shown by most hake populations (Pitcher and Alheit, 1995; Piñeiro et al., 2008). This has led international organizations to adopt recovery plans for both the Northern Stock in 2004 and Southern stock in 2005. The situation in the Northern Stock has improved. In this sense, hake in this area has reached full reproductive capacity and fishing mortality levels have been reduced to relatively safe ranges (ICES, 2008). In a 2008 advice report, the International Council for the Exploitation of the Sea (ICES), expressed alarm about the unsustainable harvesting that was still being implemented in the Southern Stock due to overfishing that was reflected in a reduced reproductive capacity. However, recent research suggests that hake grow at faster rates than previously accepted. Therefore, this underestimation in hake growth may have important consequences on stock assessment and management issues (Piñeiro et al., 2007; Piñeiro et al., 2008).

1.2. The Galician fleet in the Grand Sole

In this study, European hake captured by the Galician fleet in the Northern Stock by two different types of fishing vessels (trawlers and long liners) was analyzed from an environmental point of view.

* Corresponding author. Tel.: +34 981563100x16020; fax: +34 981547168.
E-mail address: ian.vazquez@rai.usc.es (I. Vázquez-Rowe).

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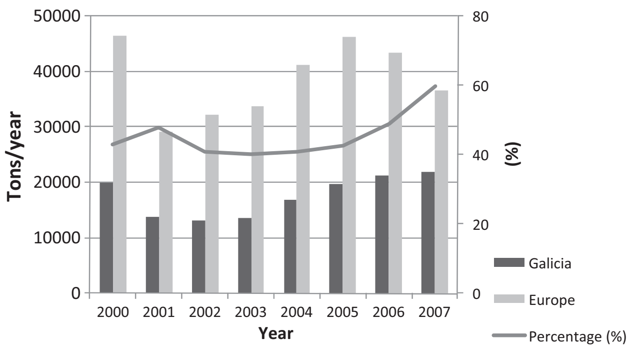

Fig. 1. Hake landings in Galicia (Black bar) and Europe (Grey bar) in the 2000–2007 period. Galician hake landing percentage over European total.
Source: FAO (2008) and Xunta de Galicia (2009).

The main areas where these fleets capture hake and other species in a multispecies fishery are mainly the Porcupine Bank (ICES Division VIIc), the West Great Sole (ICES Division VIIk), the Great Sole (ICES Division VIIj) and the Little Sole (ICES Division VIIh).

The 49 Galician long liners working in this fishery in 2008 landed their captures mainly in the ports of Burela and Celeiro (North Galician coast). The demersal target species captured by these vessels are European hake, Atlantic pomfret (*Brama brama* B.) and fork beard (*Phycis phycis* L.). Small amounts of common ling, rock fish and conger eel are also captured. Tides for this fleet usually range from 14 to 17 days. Nevertheless, European hake is by far the main target species of this fleet, roughly 60% of total captures (Porto de Celeiro, 2010). Approximately 70% of the hake caught by this fleet is then sold fresh. However, the capture obtained in the first few days of each tide reaches prices considerably lower than individuals caught in the last days of the tide (CETPEC, 2009; Xunta de Galicia, 2009).

The Galician trawling fleet working in this area is composed of a total of 63 vessels distributed in 6 ports, with an average beam above 34 m. The main species caught by these otter trawlers include megrim (*Lepidorhombus bosci* R.) and anglerfish (*Lophius budegassa* S.). European hake represents from 10% to 20% of the total landings of this fleet (Porto de Vigo, 2009). Landings of captured fish are performed mainly at the fish market in Vigo, after 15–20 day tides, slightly longer than those of long liners. Nevertheless, some vessels may occasionally land the capture in other important Galician ports such as Celeiro, A Coruña or Marín. European hake captured by these vessels is sold mainly for fresh consumption, although some may also go towards frozen products. The highest quality hake individuals can compete with those obtained through long lining activities (Xunta de Galicia, 2009).

1.3. *Purpose of the study*

Hake constitutes one of the main products in the dietary habits of Spaniards. In fact, Mercamadrid, the biggest fish market in Europe and only second to Tsukiji in Tokyo on an international scale, sold over 86,000 tonnes of fresh fish in the year 2008 (Clover, 2006). About 14,600 tonnes were adult hake alone. Another 8000 tonnes corresponded to *pescadilla*, small hake slightly above the minimum landing size (27 cm), that weighs from 500 g to 1.5 kg (Mercamadrid, 2010). Therefore, in this article an attempt was made to collect inventory data for the entire life cycle of European hake, the most common hake species commercialized in Spain.

Life Cycle Assessment (LCA) has been used previously for seafood products and has proved to be a useful environmental management tool for fishery performance evaluation (Pelletier et al., 2007). LCA methodology is used in this study to analyze the capture, landing, distribution and consumption of European hake fresh fillets caught in the Northern Stock by Galician vessels. Moreover, a comparison is established between two different types of fishing vessels (trawlers and long liners) in order to determine the environmental burdens associated with an equally marketable product (hake fillets) extracted in two different ways. In fact, hot spots identification and improvement opportunities for the two systems are important discussion points in this article. Finally, discussion relating to the quantification of improvements in fish discarding is also analyzed for the selected fleets.

2. Materials and methods

2.1. *Functional unit and scope definition*

The functional unit (FU) selected for this LCA of fresh Hake fillets was based on the recommended weekly intake of fish by the Spanish Nutrition Society. This society considers that 3 or 4 weekly fillets of fish (125–150 g per raw fillet) are the most reasonable amount a human should intake in the abovementioned period (Dapcich et al., 2004). Therefore, the selected FU was set at 500 g of raw gutted fresh hake fillet reaching the household of an average consumer in the year 2008. Due to the waste generated by the product through its life cycle, 500 g of raw fresh hake fillet correspond to 645 g of landed hake (Porto de Celeiro, January 2010, pers. commun.; Ranken, 1969)[1].

The scope of this study focuses on all the main subsystems relating to the hake extractive industry (Fig. 2). In this sense, the different operational stages of fish extraction, through landing in Galician ports were taken into account. A series of biological related impacts, such as ecosystem disruption or damage to the seafloor by fishing gears were excluded from the inventory for harvesting operations. Discards were excluded from the life cycle impact assessment (LCIA), but discard data is discussed throughout the study. Post-harvesting operations, such as the sale of fresh European hake at the fish market auction, distribution by retailers, sale at markets or supermarkets and consumption in a Spanish household were also taken into account in the study. Excluded operations included waste treatment of materials used in fishing operations. This approach from the fishery until human consumption corresponds with a “cradle to grave” analysis (Guinée et al., 2001).

2.2. *Data acquisition*

The samples used for this study are a group of 12 long liners and 9 trawling vessels belonging to the Galician Northern Stock fishing fleet, representing 24% and 14% of their fleets, respectively (Xunta de Galicia, 2009). The primary data for fishing vessel operations (Subsystem 1-SS1) were obtained through a series of questionnaires filled out by skippers from the most important trawling and long lining ports in Galicia. The questionnaires comprised a wide range of operational aspects (annual consumption of diesel, oil and antifouling paint usage, ice and net consumption, days at sea, crew size or bait use) as well as aspects related to capital goods (hull material, vessel dimensions or life span). In the case of the long lining fleet, primary data was also obtained for the bait needs of the fleet. In this sense, a background subsystem (BSS) was established in order to include bait fishing, processing and distribution. Discards for all the assessed fleets were also included in the inventory.

[1] Data regarding hake residues during the retailer and household stages of the process were obtained from a questionnaire regarding hake consumption, in which 100 Spanish citizens took part. Questions related to consumption habits, as well as to report how they purchased fresh gutted hake and the weight of the wastes involved in the retailing and consumption processes.

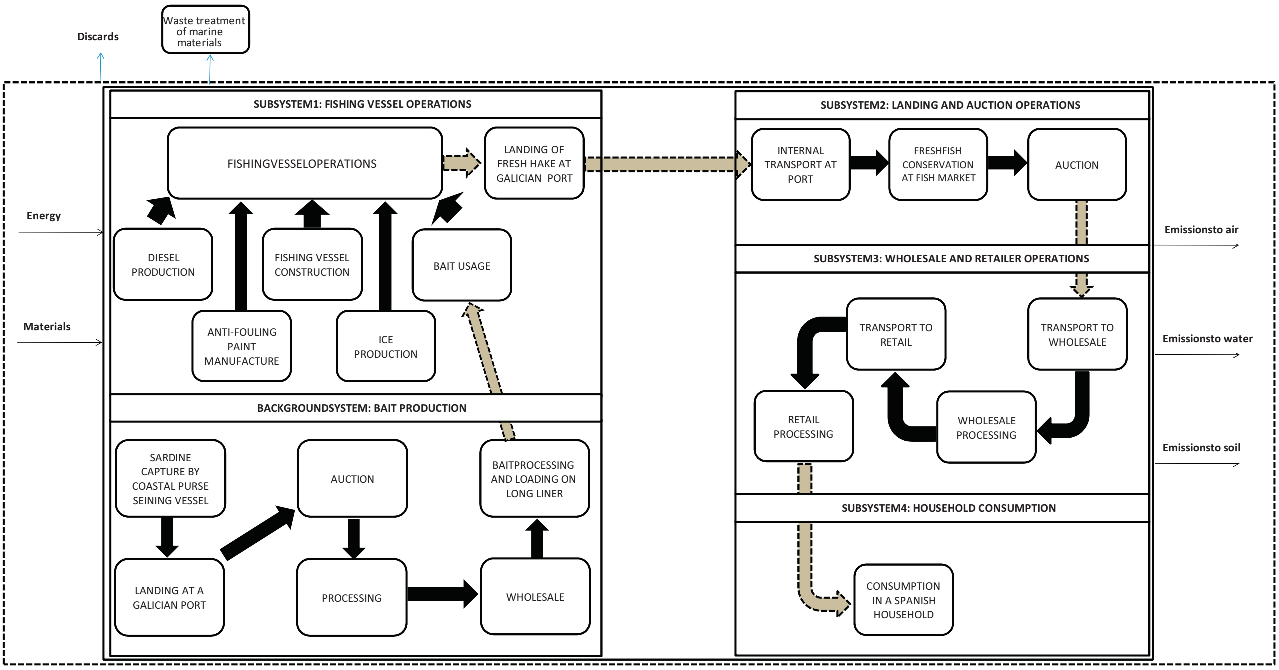

Fig. 2. System under study for European hake fillets landed at port by long liners. Blocks presented outside the discontinuous lines have been left out of the system boundaries. Black arrows represent subsystem flows, while grey arrows represent flows between subsystems.

Data for landing and auction operations (SS2) were gathered from some of the main fish auctions along the Galician coast (Porto de Vigo, 2009; Porto de Marín, 2009). Data relating to electric consumption and to the usage of different materials (pallets, plastic. . .) for fish market operations were the main inputs considered in this stage.

Data for wholesaler and retailer operations (SS3) were obtained mainly from primary data and studies referring to fresh fish wholesaling. The primary data for retailing operations obtained were mainly obtained from direct communication by local supermarkets and fishmongers, while data for wholesaling activities were obtained from bibliography data and MercaMadrid (Hospido et al., 2006; Mercamadrid, 2010). An average distance of 620 km (roughly the distance of the main Galician ports to MercaMadrid) was considered from European hake landing up to wholesaling activities. For retailing activities an average distance of 50 km was assumed.

Finally, the household consumption subsystem (SS4) entails a varied range of sources, including primary statistical data and different studies referring to seafood consumption in Spain (FROM, 2007; Mercados Municipales, 2010; Ministerio de Sanidad y Consumo, 2010). These data included shopping travel, waste treatment, packaging disposal, electric consumption or hake preparation in Spanish households.

Background data regarding the production of diesel fuel were obtained from the ecoinvent database (Frischknecht et al., 2007). In all other situations where no direct data were available, background data from the ecoinvent databases were also used.

2.3. Inventories

Inventories for the different subsystems are summarized in Tables 1–3. It is important to note the absence of a background subsystem in the trawling fleet, due to the direct harvesting characteristics of this fleet, whereas in the long lining fleet bait extraction by coastal purse seiners is needed prior to hake fishing. Finally, it is also important to highlight that SS2 through SS4 were considered common for both fleets, due to the fact that the study focuses on the

Table 1
Brief summary of the average inventory data for Subsystem 1 (data per FU).

Inputs	Units	Offshore long liners	Offshore trawlers
From the technosphere			
Materials and fuels			
Diesel	g	842	1357
Steel	g	9.07	9.72
Net	g	–	4.68
Ice	g	415	521
Boat paint	g	0.42	0.41
Anti-fouling paint	g	1.21	1.13
Marine lubricant oil	g	9.52	3.61
Outputs			
To the technosphere			
Products			
European hake	g	645.00	645.00
Co-products			
Atlantic Pomfret	g	173.7	–
Fork beard	g	62.1	–
Common ling	g	103.9	–
Rock fish	g	59.0	–
Conger eel	g	19.3	–
Megrim	g	–	1950
Anglerfish	g	–	1320
To the environment			
Discards			
Discarded fish	g	136	3276
Emissions to the atmosphere			
1. CO_2	g	2669	4301
2. SO_2	g	8.42	13.57
3. VOC	g	2.02	3.26
4. NO_x	g	60.63	97.68
5. CO	g	6.23	10.04
Emissions to the ocean			
1. Xylene	mg	110.6	103.4
2. Sea nine 211	mg	11.25	12.12
3. Ethylbenzene	mg	26.29	28.25
Waste to treatment			
Plastic to recycling	g	1.13	–
Cardboard to recycling	g	1.83	–
Plastic to landfill	g	4.24	–
Cardboard to landfill	g	0.85	–

Table 2
Brief summary of the average inventory data for the background subsystem (data per FU).

Inputs	Units	F1
From the technosphere		
Materials from processing stage		
Paperboard	g	4.4
Polyethylene (LDPE)	g	8.8
Detergent	g	0.27
Energy		
Electric energy	kW h	0.106
Transport		
Fresh sardine up to wholesale	t km	0.019
Frozen sardine up to long liner loading	t km	0.033
Outputs		
To the technosphere		
Products		
Bait (European pilchard)	g	265
F1: Offshore long liners		

same marketable product. Therefore, Table 3 is common for both trawlers and long liners.

The CML baseline 2000 method was used in order to perform the LCIA (Guinée et al., 2001). Six impact categories were included in this study: abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP) and marine aquatic eco-toxicity potential (METP). SimaPro 7 was the software used to carry out the computational implementation of the inventories (Goedkoop et al., 2008).

2.4. Co-product allocation strategies and other assumptions

- *Background subsystem.* European pilchard (*Sardina pilchardus*) bait for the long liners was considered to be fished by the Galician purse seining fleet and their landing was carried out at the most important purse seining ports along the Galician coast. This fishery is a multispecies fishery, with European pilchard, Atlantic mackerel (*Scomber scombrus*) and Atlantic horse mackerel (*Trachurus trachurus*) representing over 95% of the captures. Due to the similarity in auction sale prices for the three species, mass allocation was considered for this fishery.
- *Subsystem* 1. Both fishing fleets present a multispecies landing pattern. Therefore, allocation is an important issue to be considered (Ayer et al., 2009). Despite the fact that most LCA studies recommend the use of economic allocation for multispecies fisheries, mass allocation was considered for this study. This approach was selected due to the highly volatile price of European hake at Galician fish markets, depending on the time of the year, freshness of the product, size of the individual and many other factors that make the system too complex to analyze from an economic allocation perspective. Furthermore, as can be seen in Table 4, the use of the average sale price for European hake does not entail major differences in allocation factors with respect to a mass allocation perspective. In fact, the annual variation in hake prices is greater than the differences identified between these two allocation methods. Therefore, due to the lack of robust economical data, mass allocation was considered for both fleets. The characterization factor applied to discarded fish and residues from eviscerated fish (offal), which are usually treated in the same way as regular discards, was set at zero due to the lack of an environmental impact category linked to it (Porto de Vigo, 2009).
- *Subsystem* 3. Transport distances were calculated on the base of road guides obtained online (Guía Repsol, 2010). Truck capacity for transport to wholesalers was based on data obtained from Galician ports (Portos de Galicia, 2010) Van transportation to retailers was assumed. Finally, for this particular study it was assumed that the marketable product was cut into fillets by the retailer at sale for the consumer. Therefore, the entire pre-cooking residue created by each individual was assigned to the retailing operations.
- *Subsystem* 4. It was assumed that the fresh fillets were consumed in an average Spanish household. Post-cooking residues, including bones were assigned to this subsystem.

Table 3
Brief summary of the average inventory data for post-harvesting subsystems (data per FU) (ADP: abiotic depletion potential; AP: acidification potential; EP: eutrophication potential; GWP: global warming potential; METP: marine aquatic eco-toxocity potential; ODP: ozone layer depletion potential).

Subsystem 2: landing and auction operations		
Inputs	Units	
From the technosphere		
Materials from processing stage		
Fresh European hake	g	645
Pallets	u	6.39E−4
Polystyrene (GPPS)	g	0.91
Detergent	g	0.03
Fish boxes	g	0.59
Energy		
Electric energy	kW h	0.01
Outputs		
To the technosphere		
Products		
European hake	g	645
Subsystem 3: wholesaler and retailer operations		
Inputs	Units	
From the technosphere		
Materials from processing stage		
Fresh European hake	g	645.0
Polyethylene (HDPE)	g	12.5
Energy		
Electric energy	kW h	0.06
Transport		
Lorry transport, up to wholesale	t km	0.39
Van transport, up to retailer	t km	0.03
Outputs		
To the technosphere		
Products		
European hake fillets	g	500.0
Waste to treatment		
Disposal organic waste	g	145.0
Subsystem 4: household consumption		
Inputs	Units	
From the technosphere		
Materials		
Fresh European hake fillets	g	500.0
Tap water	g	100.0
Energy		
Electric energy	kW h	3.6E−2
Transport		
Shopping travel	p km	0.3
Outputs		
To the technosphere		
Waste to treatment		
Plastic to recycling	g	10.5
Plastic to landfill	g	39.5
Disposal organic waste	g	50.0

3. Results

3.1. Characterization results identified for LCA of fresh fillets of European hake fished by Northern Stock Galician long liners

The environmental impacts associated with the consumption of 500 g of fresh fillets of European hake showed a clear dominance

Table 4
Mass and economic allocation factors for selected European hake fishing fleets.

Offshore long lining fleet				
Species	Landings (*t*/year)	Mass allocation (%)	Value (€/kg)	Economic allocation (%)
Hake	172.7	60.7	3.72	72.1
Atlantic pomfret	46.5	16.3	1.78	9.4
Common ling	27.8	9.7	1.61	5.0
Fork beard	16.6	5.7	3.19	6.0
Rock fish-blue mouth	15.8	5.5	3.55	6.3
Conger eel	5.2	2.2	2.02	1.2
Offshore trawling fleet				
Megrim	192.0	45.8	4.50	44.7
Angler	130.0	31.0	5.58	37.5
Hake	63.5	15.1	3.72	12.2
Norway Lobster	3.0	0.7	15.19	2.4
Varied species	31.0	7.4	2.00	3.2

of the fishery phase (SS1) for all the impact categories included in the study. AP and EP were the impact categories with greater contribution to the environmental impact performed by SS1 (89.2 and 87.2%, respectively). Contributions to GWP, ODP and ADP values for SS1 were also very high, all of them above 75%. Finally, the lowest contribution of this subsystem corresponded to METP (51.6%).

The bait-linked background subsystem (BSS) presented similar contribution levels for all the impact categories included in this study, ranging from 5.8% for EP to 8.9% for ADP. This subsystem was the second most significant after SS1 for ADP, AP, EP and ODP.

The landing and auction operations stage (SS2) was found to be the lowest impact generating phase. The main contribution for this subsystem was to ADP (0.5%), whereas for GWP the contribution was of −0.3%.

The wholesaler and retailer operations subsystem (SS3) was identified as the second contributor for GWP and METP impact categories. These operations accounted for 10.1% of the total GWP and 22.6% of the total METP. Contribution to ADP and ODP were 7.1% and 6.4%, respectively, while AP and EP were below 5%.

Finally, the household consumption subsystem (SS4) presented highly variable contributions depending on the impact category assessed. In this sense, METP and ADP presented contributions of 19.2 and 7.9%, respectively; GWP had a contribution of 4.9% and the other three impact categories (AP, EP and ODP) all presented contributions below 5%. All the impact category values divided by subsystems can be observed in Table 5.

3.2. *Characterization results identified for LCA of European hake fresh fillets hake fished by Northern Stock Galician trawlers*

High quality fresh European hake captured by Northern Stock trawlers is known to compete with hake extracted by long liners in this same fishery. Table 5 also includes characterization results for the European hake caught by trawling vessels.

The fishing vessel operation stage (SS1) was the main contributor to all impact categories for the hake arriving from this fishing fleet. In fact, SS1 presented contributions higher than 88% for all impact categories, except for METP (65.3%). The landing and auction operations phase (SS2) showed very low significance regarding the overall contribution. The highest contribution for SS2 corresponded to ADP (0.4%). The wholesaler and retailer and the consumption subsystems (SS3 and SS4) had relatively high contribution to the overall METP (18.6 and 15.8%, respectively). For the rest of impact categories their contribution was always below 10%.

3.3. *Subsystem specifications regarding characterization results*

The different subsystems that were used to divide the life cycle of European hake caught by the two assessed fleets were also analyzed independently in order to attain more specific results regarding European hake capture. Therefore, as can be observed in Fig. 2, the subsystems belonging to the European hake captured through long lining methods were divided into a fish harvesting activities group (BSS and SS1) and a post-harvesting activities group (SS2–SS4) in order to analyze in depth the factors contributing to the different impact categories.

The two subsystems included in the harvesting stage (BSS and SS1) showed an overwhelming dominance of transport activities. Marine transport activities, that include diesel production and use activities, were found to represent over 90% of the contribution to environmental impacts generated in these two subsystems for all impact categories, excluding METP (86.4%). Land transport of bait only presented contributions ranging from 0.4% (EP) to 1.8% (METP and ODP). Electricity related to bait conservation showed a 3.1% contribution for METP, while for the rest of the assessed impact categories it did not reach 2%. Finally, for the remaining activities considered, the contribution was beneath 3% for all the impact categories.

For the European hake captured by trawlers, the harvesting stage only comprised one single subsystem (SS1). For this fleet marine transport contributes to at least 95% of the environmental impact for all impact categories.

The post-fishing operations included in SS2–SS4 (common to European hake captured by both fleets) were also assessed. Transport activities were the highest contributing activities for three impact categories: ODP (89.5%), AP (51.1%) and GWP (38.6%). Waste treatment operations, including wastewater, were found to be the most contributing activities for EP (59.4%) and METP (85.5%). Finally, the packaging operations throughout the three subsystems were the main contributing factor for ADP (51.2%).

3.4. *Fishery-specific environmental impacts*

When analyzing the data inventories for discarded fish, the trawling fleet presented very high levels of discards. For 1 kg of landed European hake, 5.08 kg of discards were returned to sea. Skippers reported discarding guts of individuals captured and selected for commercialization after evisceration. They also reported discarding target species individuals that do not reach minimum size requirements, non-marketable species and non-profitable species for offshore fleets, such as pouting (*Trisopterus luscus* L.) or Atlantic horse mackerel (*Trachurus trachurus* L.).

The discard rate of the long lining vessels included in the study was 0.21 kg of discards per kilogram of landed European hake. In this case, discards corresponded mainly to eviscerated residues of marketable individuals (87%). Discards per FU for both fleets are shown in Table 2.

Table 5
Characterization values associated with the Galician European hake fleets in the Northern Stock (long liners and trawlers) per FU.

Offshore long lining fleet

Impact category	BSS	SS1	SS2	SS3	SS4	Total
ADP (g Sb equiv.)	2.41E−3	2.07E−2	1.34E−4	1.94E−3	2.17E−3	2.54E−2
AP (g SO_2 equiv.)	3.49E−3	4.60E−2	8.21E−5	1.33E−3	6.83E−4	4.77E−2
EP (g PO_4^{3-} equiv.)	5.59E−4	8.43E−3	6.37E−6	2.93E−4	3.79E−4	8.98E−3
GWP (g CO_2 equiv.)	0.329	3.180	−0.013	0.416	0.203	3.83
ODP (g CFC 11 equiv.)	3.31E−8	3.92E−7	5.54E−10	2.95E−8	8.81E−9	4.64E−7
METP (g 1,4DCB equiv.)	31.70	262.00	1.58	115.00	97.70	484.18

Offshore trawling fleet

Impact category	SS1	SS2	SS3	SS4	Total
ADP (g Sb equiv.)	3.31E−2	1.34E−4	1.94E−3	2.17E−3	3.73E−2
AP (g SO_2 equiv.)	7.41E−2	8.21E−5	1.33E−3	6.83E−4	7.62E−2
EP (g PO_4^{3-} equiv.)	1.36E−2	6.37E−6	2.93E−4	3.79E−4	1.43E−2
GWP (g CO_2 equiv.)	5.13	−0.013	0.416	0.203	5.74
ODP (g CFC 11 equiv.)	6.3E−7	5.54E−10	2.95E−8	8.81E−9	6.69E−7
METP (g 1,4DCB equiv.)	404	1.58	115	97.7	618.3

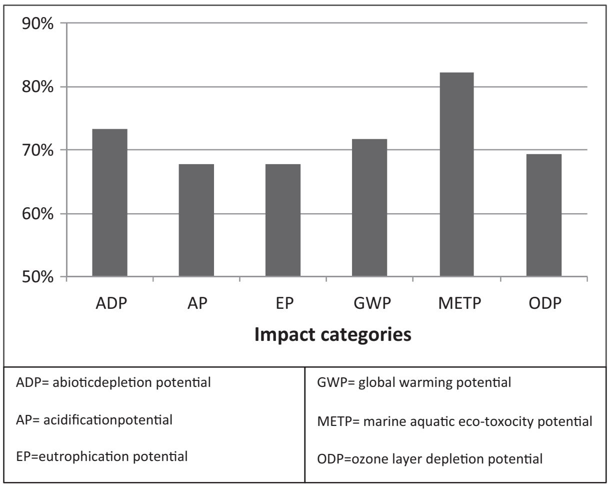

Fig. 3. Environmental performance of Northern Stock long liners respect to that of Northern Stock trawlers.

4. Discussion

4.1. Identification of hot spots and fleet comparison

Previous studies on the analysis of the environmental impacts associated with seafood products have all identified the fishing harvesting activities as the highest contributor for most impact categories (Edwardson, 1976; Thrane, 2004; Tyedmers, 2004; Watanabe and Okubo, 1989; Ziegler et al., 2003; Hospido and Tyedmers, 2005; Schau et al., 2009). In this specific study all impact categories were dominated by the fish extraction subsystem (SS1). Nevertheless, it is important to highlight the increased environmental burdens related to the European hake fresh fillets caught by Northern Stock trawlers. The total environmental impacts attributed to the product arriving from this fleet ranged from an increase of 18% for METP to 32% for AP with respect to the product arriving from the long liners (Fig. 3), despite the fact that the long lining fleet does not rely on direct harvesting, due to the use of previously extracted pelagic fish (bait) for fish extraction. This increased environmental impact for trawlers is linked mainly to the fuel-intensive characteristics of this fleet.

Inland or post-harvesting operations after fish landing represent variable environmental burdens depending on the assessed impact category. Port and auction operations (SS2) represented very low environmental impact values, while SS3 and SS4 presented high variability in their contribution to the different impact categories. In this sense, SS3 supposed over 10% of the GWP and 7.1% of the ADP for European hake arriving from long lining extraction. The impact for ADP and GWP was linked mainly to transport of the product to wholesale and to retail. The household consumption subsystem also presented relatively high contributions to ADP and GWP. However, in this case the highest contribution arrived from plastic usage for plastic bags, while consumer transport to the retailing point only represented around a fifth of the contribution to these impact categories.

Finally, it is important to note the high contribution of SS3 and SS4 to the METP impact category. This circumstance is due mainly to the high contribution generated by the waste treatments of the organic and plastic residues generated in these processes.

4.2. Quantified improvements for fish discarding

Combined LCA and Data Envelopment Analysis (DEA) methodology was applied to the long lining vessels assessed in this study in order to quantify the potential improvements of fish discarding. The use of DEA in combination with LCA has previously been used in other studies when it comes to analyzing multiple homogeneous entities from an eco-efficiency perspective (Lozano et al., 2010). It is also a useful method when impact categories are out of consensus or have not been established (Vázquez-Rowe et al., 2010). A suitable DEA model for this case study is the non-oriented slacks-based measure with undesirable outputs (SBM-Undesirable) model, which includes a so-called “bad output” (Vázquez-Rowe et al., 2010; Lozano and Gutiérrez, 2011). Besides the bad output considered for this study (fish discards), a total of 2 inputs and 1 output were included (Table 6). The use of this method was considered only for the long lining vessels, despite the fact that these vessels present lower overall discards than the trawlers (Table 1), due to minimum sample size requirements to carry out the methodology (Cooper et al., 2007). The results shown in Table 6 reveal that this methodology can be a useful tool for quantifying the potential improvements in fish discarding, even though the generated environmental impacts still cannot be assessed (Vázquez-Rowe et al., 2010). Finally, it is important to note the use of a vessel perspective for LCA + DEA analysis, rather than focusing on the analyzed product (European hake). This perspective was chosen due to the difficulty of assigning fish discards to a specific product in a multispecies fishery. Other advantages of this methodology are widely explained by Vázquez-Rowe et al. (2010).

Table 6
Minimized discard projection and input and output matrix for the long lining vessels.

DMU	Input 1 diesel (l/year)	Input 2 steel for boat construction (kg/year)	O catch value (€/year)	OBad discards (kg/year)	OBad minimized projection
F1-1	680,000	3138	1,633,578	11,500	11,500
F1-2	654,000	3450	1,583,310	7350	7350
F1-3	952,000	6320	945,792	5600	4391
F1-4	349,550	4067	472,936	4200	2195
F1-5	315,000	3983	726,600	3000	3000
F1-6	300,000	4240	691,900	7200	3212
F1-7	340,000	4182	690,700	900	900
F1-8	325,000	2829	792,410	5200	3679
F1-9	320,000	2954	643,910	3000	2989
F1-10	258,400	5000	771,328	2800	2800
F1-11	163,200	2819	732,448	3400	3400
F1-12	353,600	5067	849,152	3000	3000

4.3. Improvement opportunities

Any improvement action in order to reduce the overall environmental impact of the studied seafood product should focus on reducing the diesel consumption of the fishing vessels. In this sense, fishing effort reduction through use of energy minimization has previously been tackled by a wide range of studies (Hospido and Tyedmers, 2005; Thrane, 2006; Schau et al., 2009). Fuel reduction actions entail increased relevance when assessing Galician hake fisheries, due to the fact that European hake landings represent 22.5% (15.1% if only taking into account the two assessed fishing fleets) of the global carbon footprint of the Galician marine fishing activity (Iribarren et al., 2010). However, it is important to take into account recent studies that point out that vessels belonging to fuel intensive fleets, such as offshore trawlers, show increased efficiency of fuel related inputs respect to other considered inputs (Schau et al., 2009; Vázquez-Rowe et al., 2011). This phenomenon is strongly related to high fuel prices which have led these fleets to develop efficiency strategies. Therefore, further significant diesel consumption reductions are highly unlikely according to current operational patterns.

The fact that both evaluated fleets capture a variety of species suggests that increased fleet specialization should be enforced. If this were to be the case, European hake quota for Galician vessels should be assigned preferably to long liners. In the first place, this would reduce the seafloor disturbance of hake captures, as many LCA studies point out the increased impact of trawlers on the seabed respect to other fishing gears (Ziegler et al., 2003; Ziegler and Valentinsson, 2008). Secondly, it would increase the quality of most of the landed hake, and more of this seafood would be available for fresh consumption. Along this line, the use of mother ships to transport the fish of several vessels from the fishing zones to port would permit a considerable increase in the number of days per fishing tide. This scenario would entail important cost reductions, higher profitability for the fleet and an important reduction of environmental impacts. Finally, it would also increase the freshness of the fish landed at the Galician ports.

Despite the fact that harvesting operations are the major contributors to the total environmental impacts of the studied seafood product, a series of improvement actions can also be suggested for post-harvesting activities. In the first place, many retailers close to European hake-landing ports are starting to obtain the product directly from the fish auction, rather than buying the product off the wholesaler. This not only guarantees lower costs for the retailer and increased freshness of the product, but also reduces environmental impacts. However, for the particular scenario studied (retailing and consumption in an average household) this option is not feasible. Instead, minimization of environmental burdens can be approached through wide-ranging changes in fresh fish transportation. In this sense, the current improvement of the rail connection to Galicia from Madrid could be an opportunity to extend the rail network to the key fish-landing ports, such as Vigo, A Coruña or Celeiro, in order to encourage rail transportation of European hake and other marketable marine products to the rest of Spain (Tsamboulas et al., 2007).

4.4. Perspectives and conclusions

European hake fresh fillets captured by a series of Galician long liners and trawlers were evaluated in this study. The inventoried vessels accounted for 2645 tonnes of European hake landed, representing roughly one third of the total hake quota assigned to Spanish vessels in the Northern Stock (European Commission, 2007). The most representative conclusions obtained from the study are briefly summarized below:

- The Galician Northern Stock long lining and trawling fishing fleets were inventoried, representing 24% and 14% of the vessels of these fleets, respectively. As far as we have been able to ascertain, it is the first life cycle assessment performed on the Spanish hake fishing fleet. It is also the first attempt to analyze the environmental impact generated through the life cycle of fresh fish consumption in Spain, one of the main fish-eating nations in the world.
- Results show increased environmental impacts for activities relating mainly to marine diesel consumption and, to a lesser extent, land transportation. Other activities, such as bait processing, electric consumption and plastic and organic waste disposal demonstrated lower contributions to the entire system.
- Fresh European hake captured by long liners present reduced environmental burdens for all impact categories when compared to fillets arriving from the trawlers. Reductions ranging from 18% to 32% were obtained when using long lining vessels to supply the hake market.
- Complementary use of LCA + DEA methodology enables fish discards to be quantified and benchmarked. However, further research is needed to achieve an impact category related to this fishery-specific issue.
- Reduction of energy consumption, through improvement of vessel design and other less conventional techniques, such as redefining fishing quotas for the different fleets or the introduction of mother ships is highly recommended in order to reduce the environmental impacts related to the fishing vessels operations. Furthermore, these key factors may represent substantial cost reductions when it comes to improving the environmental performance of the assessed product.
- Other improvement strategies can be implemented throughout the life cycle of the studied product. However, these actions would not represent significant environmental reductions in the life cycle of hake fillets. Nevertheless, they may translate into important cost reductions for skippers, retailers or wholesalers.

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