Introducing the Green Protein Footprint method as an understandable measure of the environmental cost of anchovy consumption

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Abstract

Food production and consumption systems can have high impacts on the environment. In a global framework of growing concern for food security and environmental protection, the selection of food products with higher protein content and lower environmental impact is a challenge. Life cycle thinking approaches and the concept of circular economy represent an opportunity to address this paradigm.

The environmental impact of different food products is widely collected in the literature, as well as their nutritional content. However, there is not a methodology which combines both systems. Therefore, this study proposes a standardized method to calculate the Green Protein Footprint (GPF) index, a method that assesses both the environmental impact of a food product and its protein content provided to consumers. Life Cycle Assessment (LCA) was used to calculate the environmental impact of the selected products, and a Life Cycle Protein Assessment (LCPA) was performed by accounting the protein content along the supply chain. Although the GPF can be applied to all food chain products, this paper focused on European anchovy-based products (fresh, salted and canned anchovy products). Moreover, the circular economy concept was applied considering the valorization of the anchovy residues generated during the canning

process. These residues were used to produce fishmeal, which was employed in bass aquaculture. Hence, humans are finally consuming fish protein from the residues, closing the loop of the original product life cycle.

More elaborated, multi-ingredient food products (salted and canned anchovy products) presented higher GPF values due to higher environmental impacts. Furthermore, increased food loss throughout their life cycle caused a decrease in protein content. Moreover, the influence of the packaging material was also evaluated using the GPF. The use of this method reaffirmed that plastic was the best option in terms of packaging material. These results highlighted the importance of improving packaging materials in food products.

1. Introduction

The food system is already contributing to widespread environmental damage and compromising health and livelihoods of the global population (Iribarren et al. 2010a). In fact, of all economic activities, food industry has by far the largest impact on natural resource use as well as on the environment. This sector is responsible of 60% of global terrestrial loss and accounts for around 24% of the global greenhouse gas emissions (Westhoek et al. 2016). Moreover, the worldwide food waste is enhancing the pressure on the environment and causing a social concern about the enormous disparities on food availability and consumption patterns between countries throughout the world. While along 1.3 billion metric tons of edible food are wasted per year throughout the global food supply chain, around 800 million people around the world are suffering from chronic undernourishment (FAO 2014b).

Food wastes covers all the life cycle phases: from the sourcing stage, up to industrial manufacturing and processing, retail and household consumption. Nevertheless, the terms food waste (FW) and food loss (FL) have been used to define different kind of losses generated along the FSC. FL describes the losses that occur in the production, post-harvest, processing and distribution stages of the FSC, whereas FW accounts the losses at retail and consumer stages (Parfitt et al. 2010). According to the Food and Agriculture Organization of the United Nations (FAO, 2014a), FL is “the amount of food intended for human consumption that, for any reason is not destined to its main purpose” along the FSC, considering FW as part of FL.

In this sense, up to 42% of food is wasted in households, 39% losses occur in the manufacturing industry, 14% pertains to the food sector (ready-to-eat food, catering and restaurants), while 5% is lost along the distribution chain (Mirabella et al. 2014). Environmental impacts for the raw materials extraction and processing stages, as well as distribution and retailing, are found to be highly stable. However, consumer patterns are identified as highly variable depending on shopping, storage and cooking methods (Vazquez-Rowe et al. 2013). Regarding product selection, consumers may choose products that provide, for the same amount of protein, substantially different environmental impacts. Moreover, the selection of an adequate cooking method in the household may result in noteworthy environmental reductions (Vázquez-Rowe et al. 2014a).

Several European strategies are dealing to solve food system problems promoting sustainable food production and consumption patterns. From all these policies, the Food and Nutrition Security strategy is highlighted, due to its link with the increasingly interconnected challenges of natural resources scarcity, climate change and population growth, which affect the European and global food systems (European Commission, 2016). Other initiatives, such as the Bioeconomy Strategy for Europe (European Commission 2012), the Roadmap to Resource Efficient Europe (European Commission 2011) and the Blue Growth Strategy (Figure 1) are promoting food waste reduction, the improvement of industrial symbiosis practices, the recovering of waste and by-products (European Commission 2014), the attaining of a "zero waste" system based on cradle-to-cradle and circular economy concepts (Zaman 2015, European Commission 2015), and the use of sustainable practices for the management and exploitation of aquatic living (European Commission 2011b).

Nevertheless, food wasting contributes not only to increase the global environmental pressure, but also involves the loos of the nutritional value (i.e, protein content) along the FSC. In fact, on the one hand, consumers may choose products that provide, for the same amount of protein, substantially different environmental impacts. On the other hand, the selection of an adequate cooking method in the household may result in noteworthy environmental reductions (Vázquez-Rowe et al. 2014a, Self Nutrition Data 2014).

Fish and seafood, products are widely accepted to be an essential component of a balanced and healthy diet because they have a high "good fat" content and provide high quality proteins and many micro-nutrients such as vitamins and minerals (Carlucci et al.

2015). Fisheries constitute important sources of protein for human consumption, both only in terms of direct human consumption (DHC), but also indirect (IHC) (fishmeal, fish oil) (Avadí et al. 2017). In 2014, seafood accounted for about 17% of the global population´s intake of animal protein and 6.7% of all protein consumed (Abdou et al., 2018). However, there is increasing concern about the negative impacts of animal protein production, from agriculture and from aquaculture or fisheries exploiting the whole range of aquatic ecosystems (Avadí et al. 2017). Moreover, approximately 30% of food losses in Europe are related to fishing (Vázquez-Rowe et al. 2011a), mainly in the form of discards or slipping, post-harvesting, and to the processing, distribution and consumption of fish and seafood (FAO 2011). To reduce waste and enhance resource efficiency, circular economy promotes the valorization of waste to obtain new products. In recent studies, authors evaluated the environmental benefits of using waste from one sector as input for other feed/food sectors, i.e., the use of recycled food waste as enrichment for tilapia fingerlings production (Bake et al. 2009) and the use of food waste from cruise ships for its use in salmon aquaculture (Strazza et al. 2015).

Several authors have assessed the environmental impact of seafood products, i.e. canned sardines (Almeida et al. 2015), Peruvian anchoveta (Avadí et al. 2014), canned tuna (Hospido et al. 2006), European pilchard (Vázquez-Rowe et al. 2014a) and mussels (Iribarren et al. 2010b). For the particular case of European anchovy (*Engraulis encrasicolus*), waste management alternatives have been evaluated in a previous study in order to produce fishmeal, fish oil and anchovy paste (Laso et al. 2016b). In fact, it should be noted that considerable amounts of anchovy residues are generated in the production of canned and salted anchovies. These food losses represent a source of nutrients that could be used to produce feed for aquaculture, for instance, as practiced throughout the Peruvian anchovy value chain (Avadí et al. 2014). According to this, it is necessary to extend the application of the circular economy concept by means of an environmental and nutritional impact assessment of the production and consumption of European anchovy.

In this framework, the definition of a readily index that combines all the concepts covered by the European environmental food policies is necessary in order to simplify the decision making process. We thus propose a methodology to calculate the novel Green Protein Footprint (GPF) index (Figure 1), which assesses and compares both the environmental impact of a specific food product, as well as its protein content as provided to consumer.

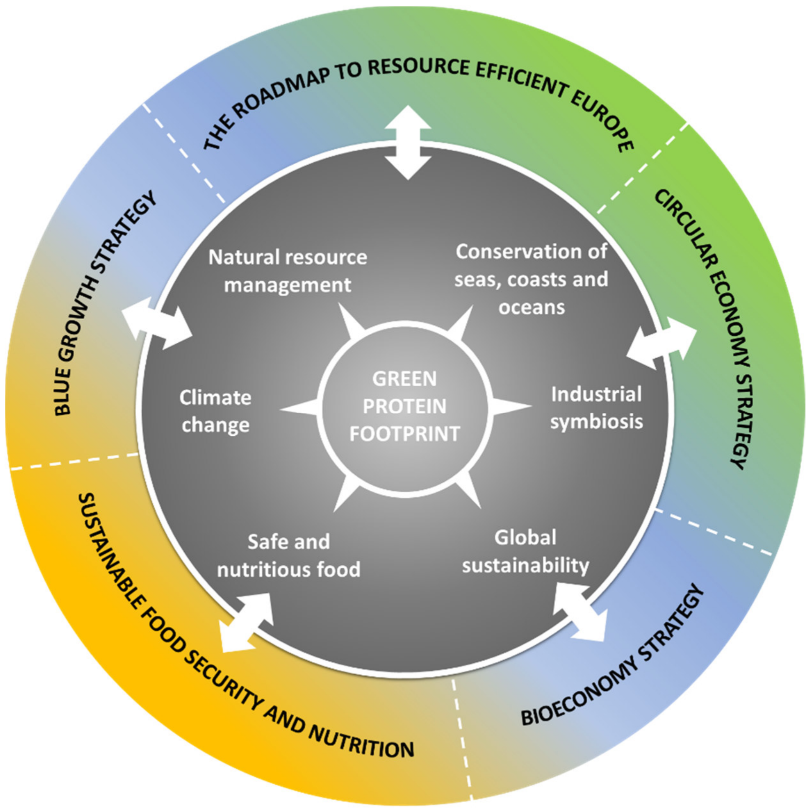

Figure 1. Interaction of the European strategies with the Green Protein Footprint (GPF).

The environmental impact is evaluated with the standardized methodology, Life Cycle Assessment (LCA) (ISO 2006). In parallel, the nutrient properties of the product are analyzed by means of the protein content along the life cycle chain. The GPF can be applied to all food chain products.

2. Material and methods

Figure 2 shows the procedure to obtain the GPF index. First, the reference scenario and the different scenarios to be studied were defined. The reference scenario considered was the extraction of the resource, which represented the base environmental impact and protein content. Thereafter, the LCA was performed on both the reference and alternative scenarios. The LCA methodology conducted a systematic accounting of environmental impacts, based primarily on the ISO 14040 standard (ISO 2006). LCA supported analysis of the total supply chain´s emissions and energy use, including the total supply chain burdens associated with material and energy inputs to production systems (Brodt et al. 2013). The environmental indicators considered in this methodology were the calculated based on Eq. S1-S8 of the Supplementary Material (SM): Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and the ReCIPE endpoint Single Score (SS). Despite the fact that other indicators could be considered, GWP, AP and EP were considered since they are commonly used LCA impact categories used in many LCA of fisheries and seafood products (Emanuelsson et al. 2008; Hospido and Tyedmers 2005; Ramos et al. 2011;Vázquez-Rowe et al. 2010a; Vázquez-Rowe et al. 2010b; Vázquez-Rowe et al. 2011b; Vázquez-Rowe et al. 2012; Ziegler et al. 2003;).

Once the LCA study was finalized, the Life Cycle Protein Assessment (LCPA) of each product (scenario) and of the reference scenario was calculated by means of the protein footprint (PF) (see Equation 1).

$$PF\ (kg) = \sum_{w=1}^{w=w} mass_w(kg) \cdot protein\ content_w(\%) \qquad \text{Eq. 1}$$

Where w represented each ingredient of the food product studied.

Although the protein content is only one of the nutritional properties of food (protein, carbohydrates, kilocalories), the edible protein energy content has already been used to perform a critical comparison of seafood products landed in Galicia by means of the edible protein energy return on investment (ep-EROI) (Vázquez-Rowe et al. 2014b).

Based on the combination between each of the four environmental indicators selected and the protein content, the anchovy products were classified into three different categories: A, B and C. An A rating represents the best environmental-nutritional option, whereas the C rating represents those supply chains with the lowest environmental-nutritional scenario. The reference values used to fix the segregation between these categories were the terciles obtained from the totality of the sample. In other words, to attain the highest rating (A) the respective environmental indicator and the protein indicator should be lower than the T1 value, whereas to achieve the C rating the indicators must be higher than T2. This methodology based on the absolute values of environmental impacts has been used by Lorenzo-Toja et al. (2016) to define the eco-efficiency of a set of 22 wastewater treatment plants in Spain.

Finally, the GPF is the combination of the LCA and LCPA (see Equation 2) and it can be calculated for each product.

$$GPF = \frac{Environmental\ impact / kg\ protein}{(Environmental\ impact / kg\ protein)_{reference\ scenario}} \quad \text{Eq. 2}$$

This method can be applied to any food product supply chain.

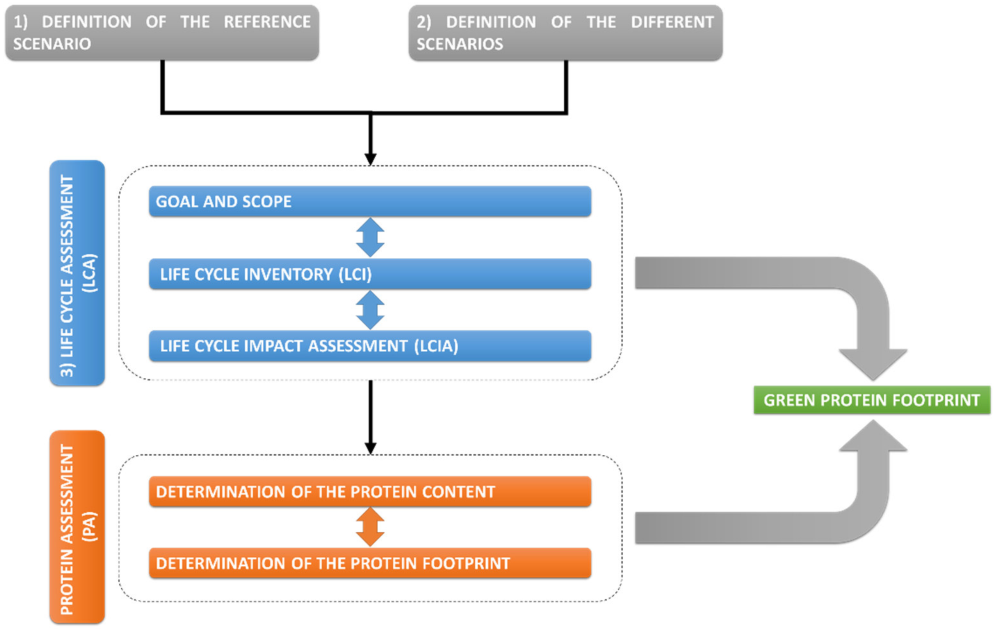

Figure 2. Green Protein Footprint (GPF) indicator methodology.

2.1. Life Cycle Assessment (LCA)

2.1.1. Goal and scope

From an LCA methodology perspective, the main objective of the present study is to propose a framework by means of the joint computation of environmental and nutritional indicators in order to attain the GPF for the life cycle of anchovy. The results of this study are intended to be of use to decision-makers within the seafood sector by providing a new integrated vision of environmental and nutritional performance. This methodology will be applied to the case study of the Cantabrian anchovy industry, taking into account direct and indirect consumptions. The Cantabrian anchovy sector encompasses a series of activities classified into three groups: anchovy fishery, processing and consumption. The selected fishery implies the extraction of fresh anchovies by the Cantabrian purse seining fleet. This fleet is composed by 41 vessels, which also fish other pelagic species, such as sardine, mackerel, horse mackerel or tuna (Laso et al. 2017b). Once the fresh anchovies are landed, they are sent to processing plants or to fish markets. In contrast to the Peruvian *anchoveta* fishery, in which almost 100% of fresh anchovy is reduced to fishmeal (Avadí et al. 2014), approximately 50% of captured anchovies in Cantabria are destined to direct human consumption. The remaining 50% goes to canning factories (Magrama 2013) to produce salted anchovies and canned anchovies in olive or sunflower oil. The latter is the most common product, defined as the "star product" of the canning industry of Cantabria.

Functional unit

The production system to be assessed is linked to the transformation of fresh anchovy into its direct human consumption products. Therefore, the functional unit (FU) was established as 1 kg of fresh, round European anchovy processed and consumed in Cantabria Region. This FU allows to assess the nutritional-environmental efficiency of the resource transformation, that is, to determine the most sustainable use of fresh anchovy.

Definition of the system boundaries

Figure 4 depicts a schematic representation of the system boundaries of the different scenarios analyzed from cradle to grave. The study included the case of the IHC of anchovy in Peru, which is converted into fishmeal and the three DHC anchovy processing alternatives (fresh, salted and canned) and their household consumption.

Based on the proposed methodology, the anchovy fishery was selected as the reference scenario. This subsystem comprised the extraction of anchovies by purse seiners in the coastal fishery in Cantabria and the landing of the catch at a Cantabrian port (Laso et al. 2017b). The auction of the catch at a Cantabrian port and the transport of the anchovies to the processing point were not considered due to the fact that the distance was below 1 km.

- Indirect human consumption (IHC) in Peru

The Peruvian fishmeal and fish oil sector produced on average (2006-2015) 1.183 million t/year of fishmeal and 230,000 t/year of fish oil, which represent 24% and 23% of the global production, respectively (Fréon et al. 2017). Approximately 98% of total landings are destined to the fishmeal and fish oil industry, and the remaining 2% is processed for human food products (Avadí et al. 2014). The three main cultured species in the Peruvian freshwater aquaculture sector are trout (*Oncorhynchus mykiss*), tilapia

(*Oreochromis* spp.) and black pacu (*Colossoma macropomum*) (Avadí et al. 2015). Therefore, in this study, it was considered that fishmeal production was destined to trout aquaculture in Peru.

- Direct human consumption (DHC) in Cantabria

  Fresh anchovies

After the fishing stage, fresh anchovies were transported to the fishmongers'. Retailing was considered throughout the region of Cantabria (Laso et al. 2016a); however, no wholesaling was assumed since the main retailers purchase the catch at the port (Vázquez-Rowe et al. 2014a). It was considered that fresh fish was transported from the harbor to fish retailer by van, and the travelled distance was 44 km. At the retailer´s, fresh anchovies were conserved on ice and consumers took them home using plastic bags. In the household, the product must be stored in freezers for 24 h at a temperature between 5 and 12ºC in an A++[1] class fridge. Three recipes were considered:

i) Fried anchovies dipped in flour. Anchovies are dipped in flour and fried in olive oil for 10 minutes. The cooking was conducted in an induction plate with a power of 2 kW (Bosh, 2017). Non-edible anchovy parts were disposed of, which subsequently ended in a landfill.
ii) Rolled in batter anchovies without head and spine. Anchovies are beheaded and their spines are removed. Finally, they are rolled in batter (with flour and egg) and fried for 15 minutes in olive oil. As in the previous case, an induction plate with 2 kW of power was considered (Bosh, 2017).The residues were comprised of the non-edible organic waste from European anchovy (approximately 38% of the life weight of the anchovy), as well as flour and oil covering these non-edible portions, which cannot be quantified. These organic residues were disposed of in a landfill.
iii) Anchovies in vinaigrette. The head and spine of each anchovy are removed and the anchovy is filleted. Thereafter, they are immersed in vinegar for 3-24 hours. After that, anchovies are drained and olive oil and garlic are added. It was

[1] Energy efficiency index (EEI), which is an indication of the annual power consumption relative to a reference consumption that is based on the storage volume and the type of appliance (refrigerator or freezer). EEI ratings are A+++, A++, A+, A, B, C, D, E, F, G.

assumed that the organic residues generated (heads and spines) are sent to a landfill.

Salted anchovies

Fresh anchovies from the port are transported to the canning plant to be beheaded and placed in layers with a bed of salt between each layer of fish for six months in a room under controlled temperature. After the curing stage, anchovies are rinsed with brine and introduced in cans covered with salt. Then, cans are hermetically sealed and packed.

Canned anchovies in olive oil

In this case, after the curing stage, the skin is removed by cold and hot water (scalding), and each anchovy is cut and filleted by hand. The anchovy fillets are packed in cans that are filled with olive oil. The cans are sealed, washed, codified and packed.

For both products, the primary packaging is composed of the aluminum can and the boxboard. Secondary packaging for the transportation of the final product consisted of corrugated cardboard boxes and low-density polyethylene (LDPE) film to wrap the packs (Laso et al. 2016a). Salted and canned anchovies were transported from the canning plant to a logistic hub, which was located 40 km from the plant and, thereafter, to a supermarket, which was located 10 km from the hub. The semi-preserved product was stored in a refrigerator of a small supermarket in the city center. In the household, the product must be stored in freezers at a temperature between 5 and 12 ºC. Salted anchovies and canned anchovies in olive oil are ready-to-eat products and they do not require any cooking (Laso et al. 2016a). The olive oil contained in the can is drained in the sink in the kitchen, although a small portion always remains covering the anchovy (approximately 10%). However, these olive oil losses were not considered because they were not quantified. For canned anchovies in olive oil, it was assumed that the entire amount of edible anchovies is ingested by the consumer and no organic wastes of European anchovy were generated in this stage. However, in the case of salted anchovies, consumers discard the spine of the anchovies, which are managed and deposited in a landfill. The can and cardboard box were assumed to be recovered assuming a recycling rate of 37% and 84%, respectively (Bala et al. 2015).

During the canning process, an important portion of the live weight of the anchovies (heads, spines and remaining anchovies) is converted into residues. To promote circular economy in the Cantabrian anchovy canning sector, remaining anchovies are used to produce anchovy paste in the canning plant (Laso et al. 2016b). On the other hand, heads and spines are sent to a reduction factory to produce fishmeal that will be used in the production of feed for bass (*Micropterus salmoides*) aquaculture in the region. Hence, humans are finally consuming fish protein from the residues linked to the production of salted and canned European anchovy, closing the loop of the product life cycle.

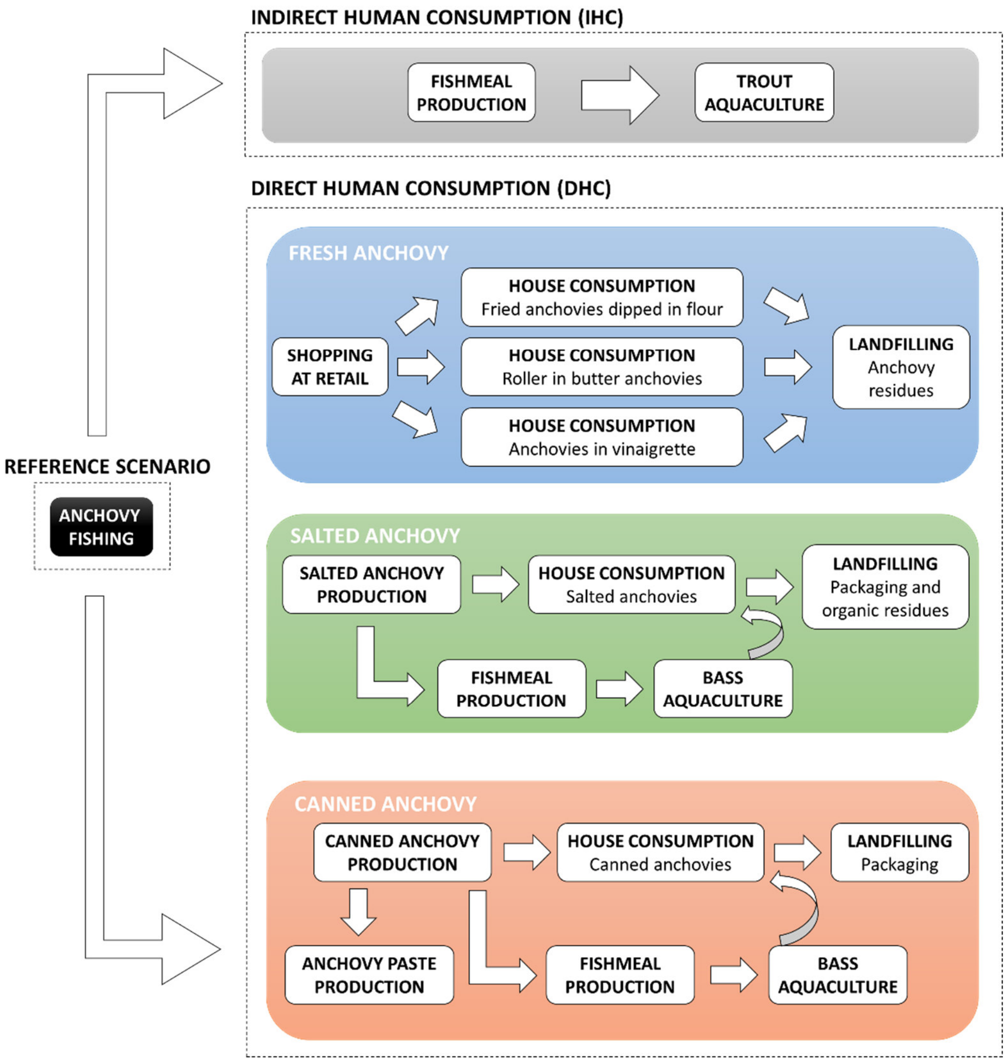

Figure 4. Block diagram for the LCA of indirect human consumption (IHC) and direct human consumption (DHC) anchovy products.

<u>Allocations</u>

Apart from obtaining protein from salted or canned anchovies (main products), fish protein was also acquired from anchovy paste and fresh bass (by-products). The same process was shared between several product systems and it was unclear to which product the environmental impacts may be allocated. To handle this problem, system expansion was applied (Figure 5). The production of tuna pâté (Laso et al. 2016b) and bass aquaculture where bass was fed by fishmeal produced from fresh anchovy (including fishing activity) were selected as the alternative systems that replace the valorization systems of the anchovy residues, taking into account the different fuel use efficiency of the tuna and anchovy fleets.

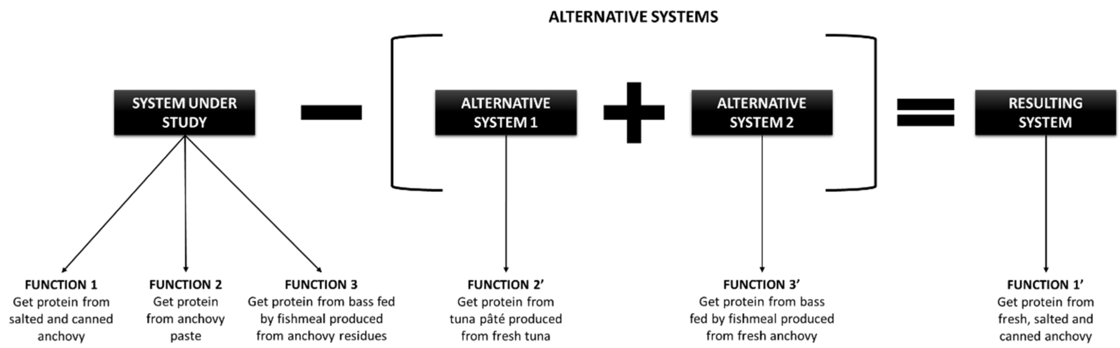

Figure 5. Scheme of the system expansion applied for the Green Protein Footprint case study.

2.1.2. Data acquisition, Life Cycle Inventory and cut-offs

<u>Data acquisition</u>

Data on the assessment of the anchovy fishery for DHC were taken from a previous study that analyzed the Cantabrian purse seining fleet from an LCA perspective (Laso et al. 2017b). The study evaluated 32 vessels targeting anchovy, taken as the reference average inventory.

Inventory data for the canning plant were mainly primary data provided by three canning plants located in Santoña (Cantabria), which produced in 2014 a total of 160,000 kg of canned anchovies. Data comprised an extensive range of operational aspects, such as the consumption of energy, fuels, water and raw materials (salt, brine, olive oil and packaging materials) and the generation of solid and liquid wastes (Laso et al. 2016a).

For the remaining subsystems, data were retrieved from bibliographical sources. Data describing the cooking methods for fresh anchovies were obtained from recipe books. Data for the anchoveta fishery for IHC, production of fishmeal and trout aquaculture were retrieved from Avadí et al. (2015) and Fréon et al. (2017), which analyzed anchovy fisheries, trout aquaculture and fishmeal production in Peru, whereas data for bass aquaculture were obtained from Jerbi et al. (2012).

Regarding the protein balance, edible and protein content of anchovy were retrieved from the database developed and provided by the School of Resources and Environmental Studies (SRES) at Dalhousie University (Peter Tyedmers, personal communication). On the other hand, the protein content of the ingredients of anchovy products was obtained from the Self Nutrition Data database (Self Nutrition Data, 2014).

Background processes, such as the production of ingredients (egg, flour, garlic, etc.) were obtained from the Ecoinvent® database (Frischknecht et al. 2007). Other ingredients, such as the production of vinegar were taken from the literature (Meneses et al. 2016; Bartocci et al. 2017).

Life Cycle Inventory (LCI)

For this study, the inventory data were divided into the five main subsystems, as shown in Tables 1-5.

Table 1. Life cycle inventory of anchovy fishing subsystem.

	Unit	**Value**
Inputs		
Steel (hull)	g	11.2
Cast iron (engine)	g	0.35
Chrome steel (engine)	g	0.18
Aluminium alloy ($AlCuMg_2$) (engine)	g	$5.42 \cdot 10^{-3}$
Nylon (seine net)	g	7.50
Lead (seine net)	g	7.46
Ethylene Vinyl Acetate (seine net)	g	3.09
Polysteel (seine net)	g	0.66
Diesel	g	345
Lubricant oil	g	2.23
Ice	g	388
Boat paint	g	0.35
Anti-fouling	g	1.75
Outputs		
Fresh anchovy	kg	1.00
Wastewater	m^3	$8.66 \cdot 10^{-4}$
Crew residues	g	190
Steel (EoL[(1)] hull and engine)	g	11.4
Nylon (EoL[(2)] seine net)	g	7.50
Ethylene Vinyl Acetate (EoL[(2)] seine net)	g	3.08
Polysteel (EoL[(2)] seine net)	g	0.66
Lead (EoL[(3)] seine net)	g	7.46

(1) Vessel dismantling
(2) Landfill
(3) Waste manager

Table 2. Life cycle inventory of fresh anchovy consumption subsystem.

	Unit	Fried anchovies with flour	Fried anchovies with egg and flour	Anchovy in vinaigrette
Inputs				
Fresh anchovy	kg	1.00	1.00	1.00
Electricity	MJ	1.20	1.80	1.27
Salt	g	0.83	0.83	64.0
Oil	g	$5.00\cdot10^{-4}$	$5.00\cdot10^{-4}$	$3.00\cdot10^{-3}$
Flour	g	333	333	-
Egg	g	-	210	-
Vinegar	m^3	-	-	$8.00\cdot10^{-4}$
Garlic	g	-	-	112
Water	m^3			$2.00\cdot10^{-4}$
Outputs				
Anchovy to consumer	kg	0.75	0.75	0.75
Anchovy residues (head and spines)	kg	0.25	0.25	0.25

Table 3. Life cycle inventory of anchovy processing in canning plants subsystem.

	Unit	Salted anchovy	Canned anchovy
Inputs			
Fresh anchovy	kg	1.00	1.00
Electricity	MJ	0.84	1.20
Salt	g	552	552
Brine	m^3	$8.20\cdot10^{-5}$	$5.67\cdot10^{-4}$
Olive oil	g	-	303
Water	m^3	$4.24\cdot10^{-3}$	$5.21\cdot10^{-3}$
Natural gas	m^3	-	$1.50\cdot10^{-2}$
Aluminium can	g	111	44.0
Cardboard box	g	132	52.0
Carton box	g	53.3	21.0
LDPE film	g	3.20	1.26
Outputs			
Anchovy products	g	817	322
Anchovy paste	g	-	35.0
Head and spines	g	183	245
Wastewater	m^3	$4.25\cdot10^{-3}$	$5.21\cdot10^{-3}$
Discards and losses	g	3.32	398

Table 4. Life cycle inventory of processed anchovy consumption subsystem.

	Unit	Salted anchovy	Canned anchovy
Inputs			
Anchovy	g	817	322
Electricity	MJ	4.38	1.76
Outputs			
Anchovy residues	g	62.0	-
Aluminium can	g	44.0	44.0
Cardboard box	g	52.0	52.0

Table 5. Life cycle inventory of fishmeal production subsystem (adapted from Fréon et al. 2017).

	Unit	Salted anchovy	Canned anchovy
Inputs			
Anchovy residues	g	183	245
Fuel use	MJ	0.44	0.589
Electricity	MJ	0.01	0.013
Antioxidants	g	0.02	0.025
Concrete	m^3	$4.65 \cdot 10^{-7}$	$6.221 \cdot 10^{-7}$
Sodium hydroxide	g	0.12	0.167
Sodium chloride	g	0.11	0.145
Metal manufacturing	g	0.01	0.01
Copper wire	g	0.001	0.001
Fishmeal bags	g	0.01	0.13
Outputs			
Suspended solids	g	1.41	1.88
Oil and fat	g	0.80	1.07
BOD5	g	2.78	3.72
Fishmeal	g	38.9	52.2
Fish oil	g	7.32	9.80

Table 6. Life cycle inventory of bass aquaculture subsystem (adapted from Jerbi et al. 2012).

	Unit	Salted anchovy	Canned anchovy
Inputs			
Electricity	MJ	5.77	7.72
Sea water	m^3	0.63	0.85
Injected oxygen	g	31.3	41.9
Biomass	g	976	1,307
Feed	g	38.980	52.180
Steal	g	1.671	2.237
Cement	g	5.961	7.980
Outputs			

Solid nitrogen	g	0.448	0.600
Dissolved nitrogen	g	2.452	3.283
Solid phosphorus	g	0.321	0.430
Dissolved phosphorus	g	0.110	0.148

Cut-offs

In relation to cut-offs, all material and energy inputs that have a cumulative total of at least 98% of the total mass and energy inputs have been included. Therefore, the inputs of ice, plastic bags and any packaging related to fresh anchovies were not considered.

2.1.3. Life Cycle Impact Assessment (LCIA)

The LCIA was conducted with LCA software Gabi 6.0 (PE International, 2014) and using a mix of impact categories from different assessment methods, following the recommendations provided by the Joint Research Centre (JRC) of the Euopean Commission (ILCD 2011, Hauschild et al 2013). The IPCC 2013 assessment method, 100-year time horizon, was used to compute the greenhouse emissions (IPCC, 2013). The CML-IA baseline method (Guinée et al. 2002) was selected to calculate acidification potential (AP) and eutrophication potential (EP). Finally, the ReCIPE endpoint method (Goedkoop et al. 2009), which compiles 18 impact categories in three different areas of protection: human health, resources availability and ecosystem diversity, was used by means of the aggregated endpoint single score (SS). This SS is computed on the basis of a weighted overall environmental profile across 16 different impact categories, computed as an endpoint indicator, that is, as a final indicator of the damage exerted on the areas of protection rather than direct emissions to natural compartments. A hierarchist perspective was selected, as opposed to egalitarian or individualist approaches, due to the fact that it considers the main policy approaches linked to time horizons (e.g., 100-year horizon for global warming) (Lorenzo-Toja et al. 2016). This approach assumes a 40% weight for human health-related impact categories, 40% for ecosystems and 20% for resources.

2.2. Anchovy protein assessment

This section shows the protein balance of European anchovy through its life cycle. As mentioned above, three different anchovy products (fresh, salted and canned in olive oil) were assessed from a nutrient perspective, based on the protein content of anchovy and its ingredients. The embodied energy of European anchovy was calculated based on the maximum edible content and the protein content per 100 g of edible portion (Table 7). The protein content per 100 g of the ingredients used in the anchovy products is collected in Table 8.

Table 7. Edible meat fraction, fillet yield and protein content of European anchovy and bass (source: Prof. Peter Tyedmers, personal communication).

	Scientific name	**Edible meat fraction (%)**	**Protein content (%)**
European anchovy	*Engraulis encrasicolus*	62	21
Bass	*Micropterus salmoides*	≈100	24

Table 8. Protein content of the ingredients of anchovy products (source: Self-Nutrition Data, 2014).

Ingredient	**Protein content (%)**
Flour	10
Vinegar	0
Olive oil	0
Salt	0
Egg	13
Garlic	9

Regarding fresh anchovies, the fluctuation in their protein content was based on the way it is cooked at the household (see Figure 6). The ingredients represented by discontinuous arrow in the flow diagram have zero protein content. The rolled in batter anchovies presented the highest protein content due to the use of flour and egg in their elaboration. Usually, consumers discarded the heads and spines of the anchovy, which were managed and sent to a landfill. Therefore, from 1 kg of landed anchovies, consumers can intake 191.8 g of protein from fried anchovies dipped in flour, 219.1 g of protein from rolled in batter anchovies or 168.6 g of protein from anchovies in vinaigrette.

For salted and canned anchovies, it was considered that anchovy wastes linked to offal and beheading were collected in the canning plant for their use in the production of feed for bass aquaculture in Cantabria. Hence, for each 1 kg (for salted and canned anchovies) of European anchovy entering the canning factory, 186 g and 245 g became residues, respectively (see Figures 7 and 8 for a graphical representation of the entire process). These residues were then sent to a reduction factory to produce fishmeal. A conversion rate of one metric ton of fishmeal per 5.5 metric tons of anchovy residues was assumed (Fréon et al., 2017).

Fishmeal arriving from anchovy residues was then mixed with other feed components to provide nourishment in bass aquaculture. The proportion of fishmeal from anchovy residues is roughly 20 % of the total (Vázquez-Rowe et al. 2014a).

The 198 g (for salted anchovies) and 261 g (for canned anchovies) of final feed to deliver to the bass aquaculture plant allowed the nourishment of 128.6 g and 169.5 g of edible bass, respectively (Jerbi et al. 2012). This fact implied a final value of 30.8 g (for salted anchovies) and 35.6 g (for canned anchovies) of protein, respectively, that humans were finally consuming, which is based on the edible content of bass (approximately 100 %) and its protein content per 100 g (24.2%) (Table 7).

Therefore, from 1 kg of captured anchovies, consumers can consume 188.7 g of protein from salted anchovies or 108.9 g of protein from canned anchovies in olive oil.

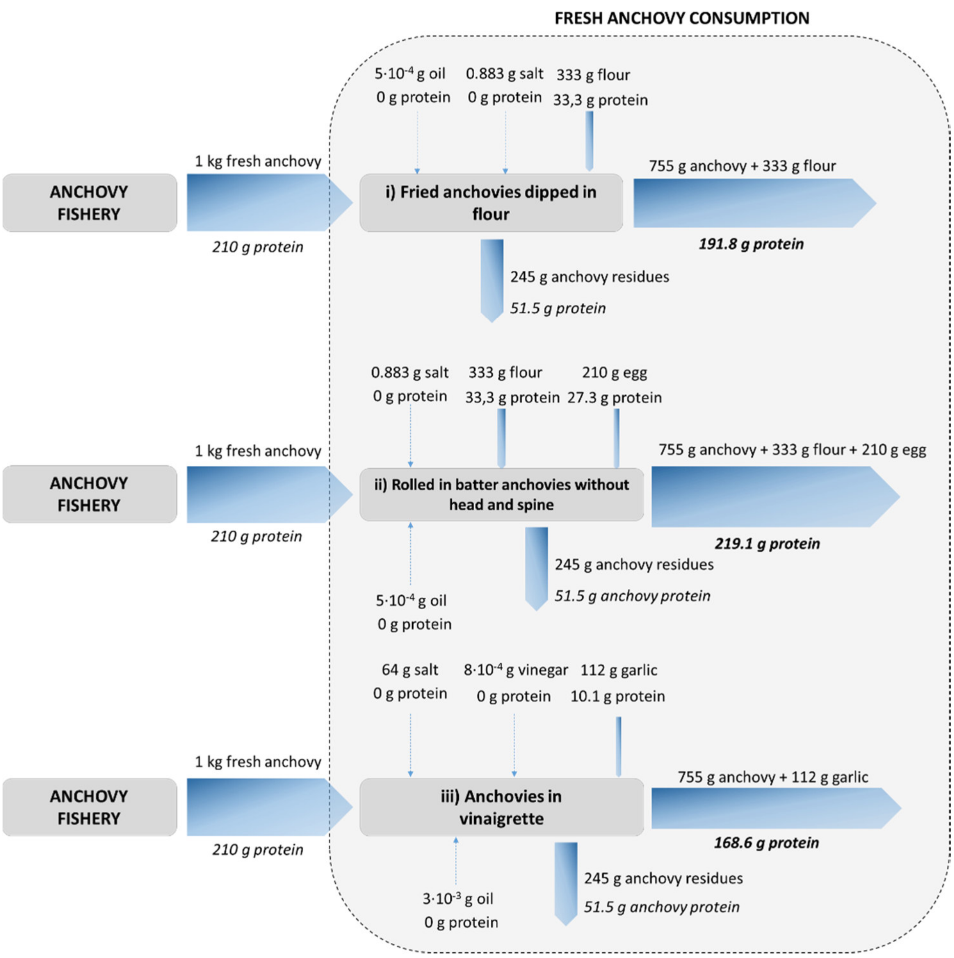

Figure 6. Schematic representation of the protein balance of fresh anchovy consumption.

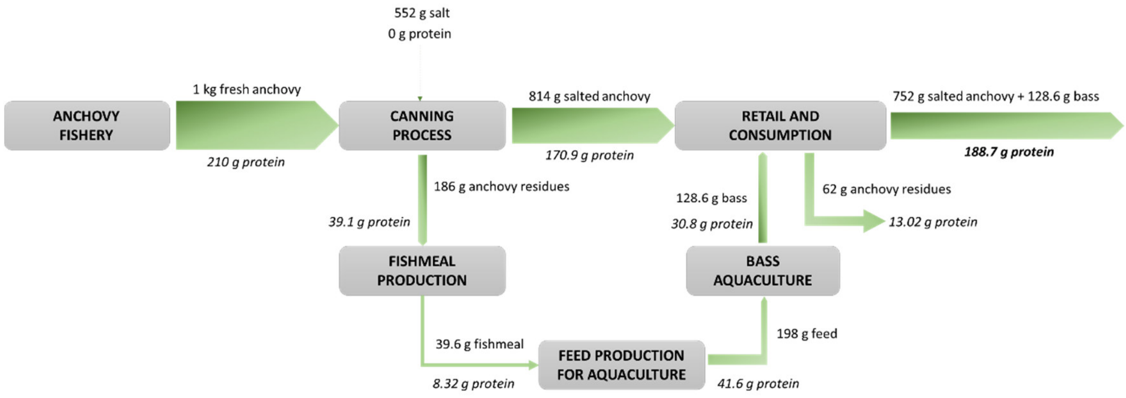

Figure 7. Schematic representation of the protein balance of salted anchovy production and consumption.

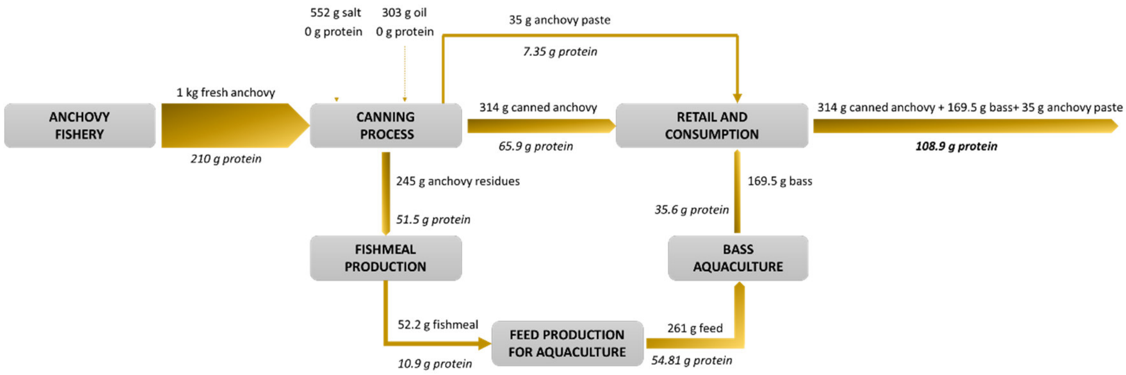

Figure 8. Schematic representation of the protein balance of canned anchovy production and consumption.

3. Results and discussion

The different environmental impacts for each environmental category considered in the study and the protein content of the scenarios under assessment are represented in Figure 9.

GWP is one of the most well-known and commonly-used environmental indicators. The energy demand of anchovy processing makes it important to include this impact category in the assessment. In fact, energy consumption, mainly in the production of primary packaging, has been reported as one of the main contributors to GWP in European anchovy LCA (Laso et al. 2016a; Laso et al. 2017a; García-Herrero et al. 2017).

Results for GWP presented in Figure 9 ranged from 0.064 kg CO_2 eq/FU for the production of Peruvian fishmeal and its use in trout aquaculture to 4.10 kg CO_2 eq/FU for salted anchovies. Fried anchovies dipped in flour constituted the best scenario with the lowest GWP value and the highest protein content. Regarding fresh anchovy products, rolled in batter anchovies presented the highest GWP due to the use of egg as an ingredient. It is noticeable that the more elaborated anchovy product, the greater GWP value. For instance, GWP related to the salted anchovies was twice that of fresh anchovy products. However, canned anchovies in oil presented a low GWP compared to the salted product due to the fact that the valorization of anchovy residues supposed an avoided burden, which reduced the environmental impact.

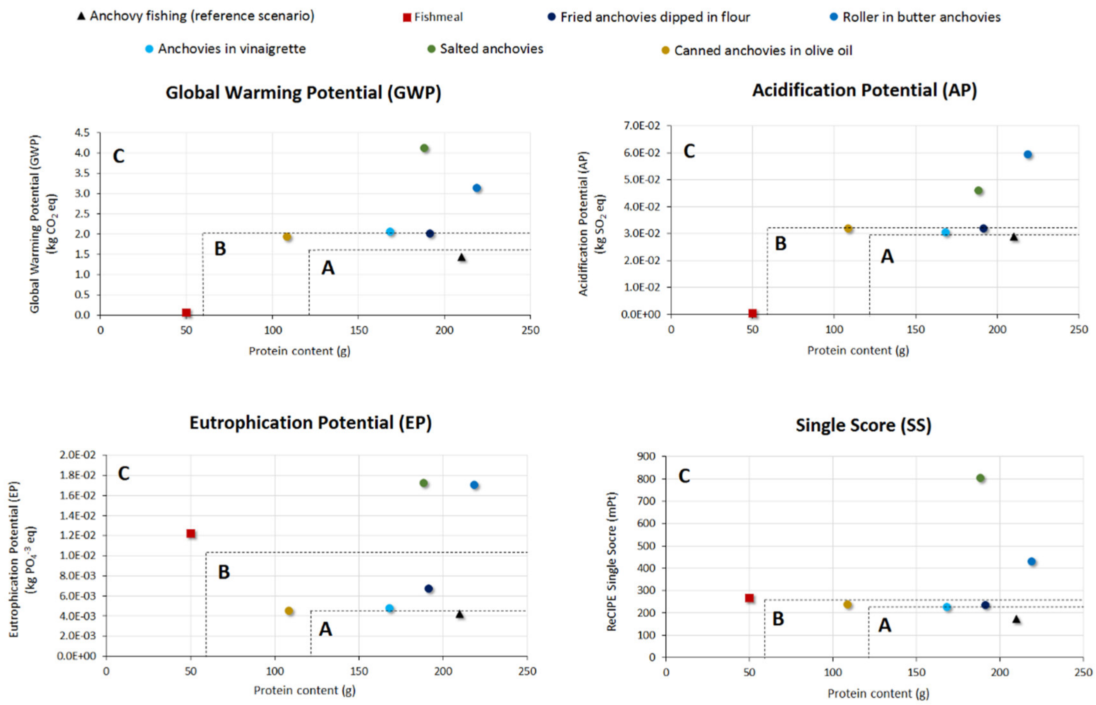

Figure 9. Global warming potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Single Score (SS) as compared to protein content per kilogram of captured anchovy converted into an anchovy product.

The trend in the other impact categories was similar to GWP. The high values of AP and EP of the rolled in batter anchovy product were due to the use of egg in its elaboration. Egg production included the animal feed inputs, energy use on the farm, water use, emissions from manure management and enteric fermentation. Capital goods were not included. The AP value of rolled in batter anchovies was 35 times higher than anchovies in vinaigrette and approximately 10 times higher than fried anchovies dipped in flour, salted anchovies and canned anchovies in olive oil. Similarly, the EP for rolled in batter anchovies was approximately 60 times higher than anchovies in vinaigrette, salted anchovies and canned anchovies in olive oil. On the other hand, the high EP value in the fishmeal scenario was due to the emissions of nitrogen and phosphorus to water in trout aquaculture (Dekamin et al. 2015).

Even though the single score of the ReCIPE endpoint methodology provides an overall picture of the environmental, the results should be interpreted with caution, taking into account the higher uncertainty within the methodology (Lorenzo-Toja et al. 2016). Nevertheless, this indicator facilitates the communication of the results to the stakeholders. The values for this indicator showed in Figure 9 range from 223 mPt (anchovies in vinaigrette) to 800 mPt (salted anchovies). In this case, the best scenarios were fried anchovies dipped in flour, anchovies in vinaigrette and canned anchovies in olive oil. It should be noted that final single score values obtained per scenario depend on the weighting system selected, which is the hierarchist perspective. As mentioned in section 2.1.3., this approach assumes a 40% weight for human health-related impact categories, 40% for ecosystems and 20% for resources.

These results show that, as the anchovy supply chain becomes more complex, the environmental impact increases. However, these products provide nutrients to consumers. Therefore, it is necessary to implement sustainability policies to reduce the generation of food wastes, enhance the use of resources and improve the management of residues. In particular, in this study, the canned anchovy product, which was the most elaborated product, presented low environmental impact per FU due to the avoided burdens associated with the valorization of anchovy residues into fishmeal for bass aquaculture. However, the generation of these wastes caused the loss of protein content. These results highlighted the importance to promote circular economy in food supply chains in order to reduce environmental impacts.

3.1. Green Protein Footprint (GPF)

When comparing the environmental pressure per kilogram of protein, the differences between products were smaller. Table 9 collects the environmental impact of each anchovy product per kilogram protein content. The GWP per kilogram of protein ranged from about 1.3 kg CO_2 eq for the production of Peruvian fishmeal and its use in trout aquaculture to 22 kg CO_2 eq for the canned anchovies in olive oil. The values of GWP were within the range of 1-86 kg CO_2 eq per kilogram of protein published by Nijdam et al. (2012) for seafood. Salted anchovies presented the highest value of GWP per kilogram of protein (21.7 kg CO_2 eq) followed by canned anchovies in olive oil (17.6 kg CO_2 eq). Regarding EP and SS impacts, the fishmeal scenario presented the highest values. As mentioned above, this was due to the emissions of nitrogen and phosphorus to water in the bass aquaculture.

Table 9. Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Single Score (SS) per kilogram of protein.

	GWP/kg protein	**AP/kg protein**	**EP/kg protein**	**SS/kg protein**
Fishing anchovy (reference scenario)	6.833	0.137	0.020	829.6
Fishmeal	1.278	0.009	0.245	5316
Fried anchovies dipped in flour	10.41	0.165	0.035	1205
Rolled in batter anchovies	14.27	0.271	0.077	1956
Anchovies in vinaigrette	12.17	0.179	0.028	1326
Salted anchovies	21.73	0.242	0.091	4254
Canned anchovies in olive oil	17.65	0.291	0.041	2165

Table 10 shows the dimensionless indicator GPF per impact category. The reference values for the normalization were those corresponding to the reference scenario (i.e., anchovy fishing): 6.833 kg CO_2 eq/kg protein for GWP, 0.137 kg SO_2 eq/kg protein for AP, 0.020 kg PO_4^{-3} eq/kg protein for EP and 829.6 mPt for SS. The production of fishmeal and its use in trout aquaculture in Peru presented the lowest GPF for GWP and AP; however, this same scenario presented the highest GPF according to the other two evaluated indicators, EP and SS. On the other hand, salted anchovies and canned anchovies in olive oil had the highest GPF based on GWP and AP, respectively.

Table 10. Green Protein Footprint (GPF) dimensionless index per impact category for each anchovy products.

	GREEN PROTEIN FOOTPRINT (GPF)			
	GWP	**AP**	**EP**	**SS**
Fishmeal	0.187	0.067	12.25	6.417

Fried anchovies dipped in flour	1.523	1.204	1.738	1.455
Rolled in batter anchovies	2.089	1.971	3.883	2.361
Anchovies in vinaigrette	1.781	1.306	1.396	1.601
Salted anchovies	3.179	1.765	4.557	5.135
Canned anchovies in olive oil	2.583	2.123	2.044	2.613

3.2. Contribution of the packaging to the canned anchovy GPF

The environmental impact linked to the production of packaging is the main hotspot of the anchovy supply chain (Laso et al. 2016a; 2017b), but also in the case of other canned seafood products (Almeida et al. 2015; Hospido et al. 2006: Vázquez-Rowe et al. 2014a). Due to the existing diversification of products in the Cantabrian anchovy industry (Laso et al. 2017a), there is a high variety of anchovy products with different packaging formats: glass container, plastic tub, covered plastic tray, plastic bucket, tinplate can, aluminum can, etc. In addition, as mentioned in section 2.1.1., no packaging for fresh anchovies was considered. However, due to recent changes in lifestyle some fish markets provide beheaded and filleted fish in plastic packaging. If this pattern is extended, it should be considered in future studies.

This section aims to evaluate the influence of the packaging material using the GPF indicator. The assessment was performed considering that the packing material of canned anchovies in olive oil could be aluminum, tinplate, glass and plastic. It should be highlighted that, as mentioned in the description of the system boundaries, packaging was recycled assuming recycling rates published by Bala et al (2015). Table 11 collects the GPF per impact category for each canned anchovy in olive oil product assessed. Moreover, the GPF of the canned anchovies in olive oil without packaging was also calculated in order to observe the influence of the packaging in the canned anchovy life cycle. The aluminum can presented the highest GPF values according to GWP and EP indicators, whereas the glass jar had the greatest GPF values to AP and SS. Plastic appears to be the best option because it shows the lowest value of GPF for all impact categories studied.

In order to compare the results obtained in the sensitivity analysis with the other anchovy products, the GPF based on the SS indicator was selected because it computed 18 environmental categories in a single value, facilitating the decision-making process.

Figure 10 displays the GPF based on the SS indicator of each anchovy product compared with the canned anchovies in the olive oil scenario using different packaging materials. The scenario included within the dotted line represents the GPF of the canned anchovies in olive oil with and without packaging. The best scenarios were those in which the anchovy was less processed, i.e., fried anchovies dipped in flour, anchovies in vinaigrette and rolled in batter anchovies. The worst scenario was the production of fishmeal to use it in trout aquaculture. As expected, the GPF of the canned anchovies in olive oil without packaging was lower than with different packaging formats. However, this difference was not as notable as initially presumed due to the recycling packaging materials, since the EOL reduced their environmental impact. These results highlight the need to improve the packaging of the canning products in general.

Table 11. Green Protein Footprint (GPF) per impact category for each packaging material.

	GREEN PROTEIN FOOTPRINT (GPF)			
	GWP	**AP**	**EP**	**SS**
Canned anchovies in olive oil without packaging	2.224	2.013	1.997	2.174
Canned anchovies in olive oil in aluminum can	2.583	2.123	2.044	2.613
Canned anchovies in olive oil in tinplate can	2.561	2.100	2.037	2.511
Canned anchovies in olive oil in glass jar	2.550	2.206	2.042	2.630
Canned anchovies in olive oil in plastic tub	2.513	2.081	2.029	2.490

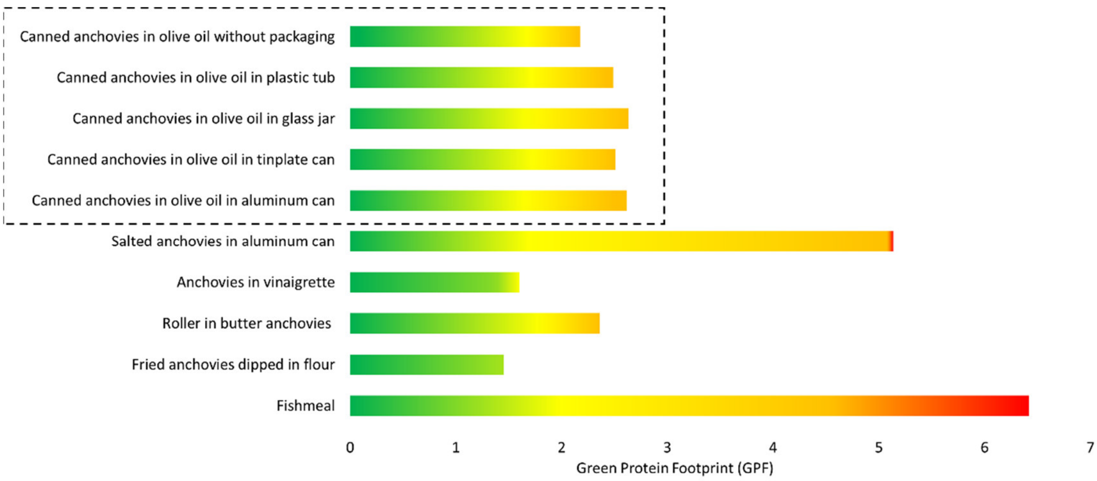

Figure 10. Green Protein Footprint (GPF) based on the Single Score (SS) indicator (ReCIPE) of each anchovy product and the different packaging materials for canned anchovies in olive oil.

4. Conclusions

The environmental impact assessment linked to food production together with global chronic undernourishment make necessary the implementation of policies that promote food security and the bioeconomy. This paper combines two terms that are of vital importance to our global population: environmental impact and nutrition, developing a new sustainable index, the Green Protein Footprint (GPF). This index assesses and compares both the environmental impact of a food product and its protein content provided to the consumer. In a framework of growing concern for food security, the GPF index can help facilitate the decision-making process in order to introduce measures that will lead to increase sustainability and reduce environmental cost of food production systems.

In this study focused on the anchovy canning industry, we have identified that more complex food products, salted and canned anchovy products, presented higher GPF because their environmental impact was greater (3.179 and 2.583, respectively, when the GPF is calculated from the GWP). Moreover, food loss throughout the life cycle of the processes assessed caused that the protein content of these product decreased. Therefore, equilibrium is necessary between environmental impact and food protein content.

Consumers and producers are the main actors involved in the decision-making process. Food loss along the life cycle causes that the protein content of the product decreased. Food waste prevention along the food supply chain and packaging materials are challenges for the food industry that require further analysis.

The life cycle thinking approach from an environmental and nutritional point of view will contribute to a transition towards a circular economy which will foster sustainable food production and consumption.

Acknowledgements

The authors thank the Ministry of Economy and Competitiveness of the Spanish Government for their financial support via the projects GeSAC-Conserva: Sustainable Management of the Cantabrian Anchovies (CTM2013-43539-R) and CERES_Project: Food Production strategies for climate change mitigation: towards a food circular economy (CTM 2016-76176-C2-1-R). Authors thank Julia Celaya for her technical support. Jara Laso thanks the Ministry of Economy and Competitiveness of Spanish Government for their financial support via the research fellowship BES-2014-069368.

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