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Packaging environmental impact on seafood supply chains – A life cycle assessment (LCA) review

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Keywords:	food packaging, life cycle assessment (LCA), industrial ecology, plastic
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Abstract:	Packaging is fundamental for food preservation and transportation but generates an environmental burden from its production and end-of-life treatment. This review evaluates packaging contribution to the environmental performance of seafood products. Life cycle assessment (LCA) studies were evaluated by both qualitative and quantitative analysis. The qualitative analysis assessed how direct (e.g. packaging material) and indirect impacts (e.g. influence on seafood loss and waste) have been considered, while the quantitative analysis evaluated packaging contribution to products' weight and climate change impact. Qualitative analysis revealed that seafood LCAs focus mainly on direct environmental impacts arising from packaging materials; for which some articles conducted sensitivity analysis to assess materials substitution. Recycling was found to be the most common recommendation to diminish direct potential environmental impacts arising from packaging end-of-life. However, recovery rates and other end-of-life options, such as reuse, should be considered. Quantitative analysis revealed that the production of cans contributes significantly to the overall climate change impact for canned products. On average, it contributes with 42% of product's climate change impact and 27% of products' weight. Packaging has a lower contribution when considering freezing, chilling and other post-harvesting processing. It represents on average less than 5% of product's climate change impact (less than 1 kg CO2 eq/kg seafood) and 6% of product's weight. Packaging material production is more relevant to aluminum, tinplate and glass than for plastic and paper. Therefore, it is essential to accurately include these materials and their associated processes in inventories to improve the environmental performance of seafood products.

Article Type: Research and Analysis

Title: Packaging environmental impact on seafood supply chains – A life cycle assessment (LCA) review

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Keywords: canning, fish, life cycle assessment, industrial ecology, food packaging, plastic.

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1. INTRODUCTION

Food packaging has the main function of protecting the product from any damage, delivering food in good condition to consumers and contributing to avoid food loss and waste (FLW) (Russell, 2014). It enables distribution, adds convenience by facilitating food accessibility and informs about the content, shelf life and storage conditions (Pauer et al., 2019). A demand for novel food packaging, able to increase products shelf life and reduce negative impacts of packaging on the environment, has been growing. However, plastic from packaging is ever more a source of pollution associated to marine litter due to its durability, with reported impacts on several marine species, including fish destined for human consumption (Xanthos & Walker, 2017). In fact, approximately 8.3 million tonnes of plastics reach the ocean on an annual basis, both in the form of microplastics, mainly due abrasion of tyres and city dust, and macroplastics, mainly due to waste mismanagement (Ryberg et al., 2018). Causes for plastic leakage are attributed to incorrect disposal by consumers, but can also be linked to the lack of a proper end-of-life management (Abejón et al., 2020). For instance, the waste-management systems are fairly rudimentary in many developing countries (Vignali, 2016). Given increased global demand for food, there is likely to be an enhanced focus on food security, waste mitigation, and resource utilization, which will also influence packaging and adjacent industries (Rowan & Galanakis, 2020).

Consumers usually have a limited perception, they are generally exposed only to packaging from retailing and waste stages of the supply chain (Russell, 2014). However, packaging cannot be separated from the product chain and its different packaging levels (Denham et al., 2015). The first level, primary packaging, refers to the packaging in direct contact with the product (e.g. aluminum can), while secondary packaging corresponds to subsequent layers of material which contain one or more primary packaging (e.g. cardboard box), and tertiary packaging is designed for the purposes of transport, handling and/or distribution and typically is not seen by consumers (e.g. pallets) (ISO 2106). The production, use, and disposal of packaging are associated with a multitude of potential environmental impacts (Flanigan et al., 2013). Direct environmental impacts are the effects occurring during the production, transport or recycling of packaging materials (e.g. metal, paper, glass, plastic) (Lindh et al., 2016). While indirect environmental impacts come from the influence of packaging on the food product's life cycle (e.g. the effect of packaging on reducing FLW or on transport efficiency, handling and storage through the supply chain) (Molina-Besch et al., 2019).

Research shows that the environmental burden from FLW often exceeds that of packaging (Wikström et al., 2014). If FLW increases due to inefficient packaging, a higher environmental cost of the product could result afterwards coming from all the resources devoted to food production that are wasted. In the case of seafood, packaging can be more relevant since it is highly prone to spoilage in comparison to other food (Love et al., 2015). It is estimated that 36% of the total edible seafood is lost or wasted in Europe throughout the supply chain, between landing and consumption (Gustavsson et al., 2011).

Life cycle assessment (LCA) is a methodology that evaluates the potential environmental impacts associated with a product by inventorying and evaluating the inputs (e.g. energy and raw materials) and outputs (emissions to air, water and soil) over the entire product's life cycle (Del Borghi et al., 2020). LCA studies on food production have shown that later stages in the supply system, such as packaging, retail, and transport, all combined contribute to less than 14% to climate change impact (Poore & Nemecek, 2018). However, packaging can contribute significantly to climate change impacts of certain products (e.g. canning), when packaging production is the major hotspot due to high energy needs for materials' production (Poovarodom et al., 2012). On the other hand, packaging can also represent an opportunity to reduce impacts from food by avoiding food waste (Heller et al., 2019). At the consumption stage, 20% to 25% of household food waste can be related to packaging design attributes, including the attributes easy to empty and the correct quantity (Williams et al. 2012).

The number of LCA studies related to seafood has risen considerably in the 2000s, with several studies assessing the impact of different seafood products (Avadí et al., 2020; Bohnes et al., 2019). Yet, seafood is a complex sector consisting of many species caught by different fishing gears (Parker et al., 2018; Parker & Tyedmers, 2015) or reared in a variety of aquaculture systems and environments (MacLeod et al., 2020). Most seafood LCA studies, either from fisheries or aquaculture sources, focused on the production stage of seafood products, overlooking packaging and processing stages contribution. Fish preparation for fresh consumption undergoes basic processing tasks (i.e. cleaning, gutting), but processing methods such as canning, curing (salting-curing) or freezing require further processing operations (Vázquez-Rowe, Villanueva-Rey, et al., 2012). Studies that covered the whole seafood chain showed that packaging contribute to less than 15% to the climate change for frozen, chilled and cooked seafood products (V. Putten et al., 2015; Svanes et al., 2011b; Vázquez-Rowe et al., 2011). However, in the case of canned seafood, packaging can contribute significantly to the product's climate change impact, where the production of packaging (tinplate and aluminum) can be the major hotspot (Avadí et al., 2014; Iribarren, Hospido, et al., 2010; Vázquez-Rowe et al., 2014). In addition, LCA studies demonstrate that important environmental savings may be achieved by optimising packaging for seafood products (Almeida et al., 2015; Avadí et al., 2014; Pardo & Zufía, 2012). However, there is need for more empirical data on food packaging (Molina-Besch et al., 2019), with specific information to cover different environmental requirements, including material, weight, shape and end-of-life phase (Molina-Besch, 2016).

Consequently, this timely review used seafood LCA-published studies in order to evaluate features and find patterns related to packaging environmental assessment. The aim of this study was to make a systematic review of packaging included in seafood products LCAs. For this purpose, two distinct analysis were performed: a) qualitative, to evaluate how packaging direct and indirect environmental impacts have been addressed and how they can decrease; and b) quantitative, to evaluate packaging contribution (weight and climate change impact) on seafood products' life cycle; together with a discussion on main challenges to improve seafood packaging sustainability identified.

2. METHODS

2.1 Literature search strategy and inclusion criteria

The review was carried out by conducting searches for studies published in peer-reviewed indexed journals in electronic databases (Web of Science, Scopus, Google Scholar and Science Direct), during the last 20 years (from January 2000 to December 2019). The combined search terms "fish" or "seafood", "LCA" or "life-cycle" or "environmental" or "environment", and "packaging", on titles, abstracts and keywords, were considered as presented in Figure 1. Expert opinions, conference articles, and grey literature were excluded from the literature search. Only articles representing a full-length article written in English and published in a peer-reviewed journal were selected.

The literature search resulted in a total of 322 potentially relevant articles. A refinement was made by removing duplicates (177 articles) and excluding studies with the following criteria: if not directly related to LCA or not presenting an LCA case study (59 articles); it not including packaging in the scope (35 articles); if being a review article and not having detailed information about products packaging like case studies (12 articles); and if not related to seafood products (7 articles). Cumulatively, this search resulted in the selection of 32 seafood LCA case studies including packaging.

2.2. Analysis of LCA articles focusing on packaging

The products identified in each article were categorized by species, production type (fishery or aquaculture), post-harvest processing (canning, chilling, freezing, or others), primary and other packaging levels materials, and geographic scope. Besides, methodological choices from each article were also identified, in particular functional unit, system boundaries, allocation method, life cycle impact assessment method and impact categories used. All categorize information extracted from the articles is included in Table S1 of supporting information (SI). A list of seafood products found in the 32 articles was obtained and packaging contribution to each product, based on quantitative data from weight and climate change impact figures, and qualitative data on inclusion of environmental impacts of packaging in life cycle steps, were collected and analyzed.

2.2.1 Qualitative analysis

A qualitative analysis discussing direct and indirect environmental impacts of packaging in the LCA studies selected was performed following the analytical framework developed by Molina-Besch et al. (2019). This framework evaluates the inclusion of direct and indirect environmental impacts of packaging in each product's life cycle step, the development of sensitivity analysis to investigate how the results would change if conditions were different, and the proposal of recommendations. The following life cycle steps were considered: 1) primary packaging material (direct impact); 2) secondary packaging material (direct impact); 3) food loss and waste (indirect impact); 4) seafood transport from producer to retail (indirect impact); 5) energy consumption of seafood storage (indirect impact); 6) seafood preparation by households (indirect impact); 7) packaging end-of-life (direct impact), and; 8) emerging innovations (indirect impact).

The direct environmental impacts coming from packaging material and its end-of-life, come mainly from material production and its waste management process, which might involve different operations. In the other life cycle steps, where indirect impacts were considered, it was evaluated the influence of packaging in the avoidance of FLW, in energy consumed for storage, in the preparation method by households and, in which way packaging can influence innovations proposed to the products. Therefore, to each life cycle step, the inclusion (Yes/ No) of: 1) packaging in the scope of the LCA study; 2) sensitivity analysis; and 3) recommendations, was evaluated. Besides, specific recommendations on measures to improve packaging were identified and described.

2.2.2 Quantitative analysis

In order to perform a quantitative analysis, life cycle inventory (LCI) data and life cycle impact assessment (LCIA) results from the selected articles were collected. When available, quantifiable packaging data related to its weight from LCI data and the LCIA results for the climate change impact category were retrieved from the articles. When this data was not available in the articles, it was directly requested to authors. It should be noted that system boundaries, assumptions and background LCI databases are not the same in all articles. For example, post-harvest stages to all products include at least a cradle-to-gate assessment, but some articles also included retailing (cradle-to-market) or end-of-life of packaging (cradle-to-grave). Therefore, this quantitative analysis does not compare results between different products but rather provides a range of results typically found in literature. The data was compared between different type of post-harvest processing - canning, freezing, chilling, and others (e.g. cooking), or main packaging material - aluminum, tinplate, plastic, paper, wood, and glass.

The data obtained was gathered from 27 articles of the 32 selected. Five article were excluded from this analysis because their data set was identical to data presented in other articles already included in the analysis (Iribarren, Moreira, et al., 2010b; Svanes et al., 2011b; Vázquez-Rowe, Villanueva-Rey, Moreira, et al., 2013) or it was not possible to reach any quantitative data for packaging (Mungkung et al., 2006; Nhu et al., 2015). The list of articles and data retrieved is synthetized in Table S2 of the SI.

The LCI data collected was investigated to quantify weight contribution of packaging to the final product weight (Cw_{pack}, %) (Eq. 1):

$$Cw_{pack} = \frac{w_{pack}}{w_{pack} + w_{food}} \quad (1)$$

where, w_{pack} is the packaging weight (kg) and w_{food} is the food packaged weight (kg). Packaging weight includes both primary and secondary packaging. Food weight includes both seafood and other ingredients (e.g. olive oil or other sauce type).

For LCIA, the climate change impact category was selected because all studies from the literature search included this impact category, being its impacts based on characterization factors from the Intergovernmental Panel on Climate Change (IPCC). Other impact categories were not included in the analysis because they are not common to all studies and they rely on different impact assessment methods. By focusing on climate change category, we covered only environmental impacts related to greenhouse gas emissions, to which food production plays an important role in global emissions (Poore & Nemecek, 2018). Tracking and reducing emissions specifically from seafood products could contribute to limit climate change and to tackle this global achievement.

Therefore, LCIA results were investigated to quantify climate change contribution of the packaging (Ccc_{pack}, %) to the total climate change impact considered. The Ccc_{pack} was obtained either by collecting directly the contribution from the article or by using Eq. 2:

$$Ccc_{pack} = \frac{cc_{pack}}{cc_{total}} \qquad (2)$$

where, cc_{pack} is the packaging climate change impacts (kg CO_2 eq) and CC_{total} is the total climate change impacts over the product life cycle (kg CO_2 eq). It should be noted that when the LCIA data received from authors was that the cc_{pack} contribution was very small, a contribution of 0.5% was considered for the analysis. This was the case of four different products: chilled salmon (Parker, 2018), chilled mussels (Iribarren, Moreira, et al., 2010b) and chilled and frozen mussels (Iribarren, Moreira, et al., 2010c).

3. RESULTS & DISCUSSION

The main information arising from seafood LCA studies that were selected from the literature review are presented in Table 1. In cases where a single study yielded several products, these were considered to be separate products if being from different species or if they were produced from different processing methods. Therefore, from the 32 articles selected, a total of 50 products were retrieved for analysis. A higher number of articles selected presented products from fisheries (n=21) compared to aquaculture (n=10), and one study does not specify the production source. The products analyzed included 24 species, though more species could be included since some studies only mention the species group that may correspond to more than one species (e.g. tuna). The species were then organized in 15 species groups (Table 1), including fish (anchovy, catfish, cod, hake, salmon, sardine, tilapia, trout, and tuna), crustaceans (lobster, shrimp, and prawn), cephalopods (octopus) and bivalves (mussels and oysters).

Table 1. Main information of the seafood LCA studies selected (*Packaging materials: LDPE - Low density polyethylene; HDPE - High density polyethylene).

#	Reference	Species group	Production type	Functional unit	Post-harvest processing	Primary packaging *	Other packaging *
1	Almeida et al., 2015	Sardine	Fisheries	1 kg of edible canned sardines in olive oil	Canning	Aluminum can	Corrugated board
2	Avadí et al., 2014	Anchovy	Fisheries	1 kg of fish product	Canning	Tinplate can	-
					Canning (curing)	Tinplate and aluminum can	
3	Avadí et al., 2015	Tuna	Fisheries	1 t of tuna product	Canning	Tinplate can	-
					Canning (pouch)	Retort pouch (plastic)	
					Freezing (vacuum bagged)	Thermo-shrinkable bag (plastic)	
4	Driscoll et al., 2015	Lobster	Fisheries	1 t of live lobster	Chilling	Corrugated cardboard, polystyrene, and cotton fiber	-
5	Farmery et al., 2014	Lobster	Fisheries	1 kg of live lobster	Chilling	Polystyrene boxes with wood wool, ice packs	-

6	Farmery et al., 2015	Prawn	Fisheries	1 kg of frozen banana prawn	Freezing	Cardboard box	-
7	Hospido et al., 2006	Tuna	Fisheries	1 t of raw tuna entering the factory	Canning	Tinplate can	Cardboard box, plastic film
8	Iribarren et al., 2010	Mussels	Aquaculture	Triple pack of round can of mussels	Canning	Tinplate can	Cardboard
9	Iribarren, Moreira, et al., 2010	Mussels	Aquaculture	65 t of CaCO3 products and 278 t of mussel pâté	Canning	Tinplate can	Cardboard, packaging film
10	Iribarren, Moreira, et al., 2010b	Mussels	Aquaculture	1 kg of mussels product	Canning	Tinplate can	Cardboard, LDPE bag
					Chilling	Mesh bag of HDPE	
11	Iribarren, Moreira, et al., 2010c	Mussels	Aquaculture	35 kg of canned mussels	Canning	Tinplate can	Cardboard (can) and LDPE bag
				40 kg of fresh mussels	Chilling	Mesh bag of HDPE	LDPE bag
				20 kg of frozen mussels	Freezing	Paperboard and plastic	LDPE bag
12	Laso et al., 2017	Anchovy	Fisheries	1 kg of raw anchovy entering the factory	Canning	Aluminum can	Cardboard boxes, LDPE film
						Tinplate can	
						Glass jar	
						Plastic packaging	
13	Laso et al., 2018	Anchovy	Fisheries	1 kg of fresh European anchovy entering the factory	Canning	Aluminum can with cardboard box	Corrugated and cardboard boxes, LDPE film
					Canning (curing)	Aluminum can with cardboard box	Corrugated cardboard boxes, LDPE film
14	Mungkung et al., 2006	Shrimp	Aquaculture	1.8 kg of frozen shrimp	Freezing	Material not specified	-
15	Nhu et al., 2015	Catfish	Aquaculture	1 t of Pangasius fillets leaving the factory	Other (freezing and modified atmosphere packaging)	Polyethylene and cardboard	-
16	Pardo & Zufia, 2012	Fish (sp not identified)	Not specified	1 kg of the pre-cooked dish of fish and vegetables	Other (cooking)	Polypropylene	-
17	Parker, 2018	Salmon	Aquaculture	1 kg of head-on gutted salmon	Chilling	Polyethylenelined polystyrene boxes	-
18	Pelletier & Tyedmers, 2010	Tilapia	Aquaculture	1 t of tilapia	Freezing	Cardboard and plastic	-
19	Silvenius et al., 2017	Trout	Aquaculture	1 t of skinless fillet of fish	Chilling	Plastic	-
20	Svanes et al., 2011	Cod	Fisheries	1 kg of cod wetpack	Freezing	Polyamide and polyethylene	Polyethylene film, wood pallet, carton
				1 kg of frozen cod	Freezing	Polyamide and polyethylene	Corrugated board, wood pallet

				1 kg of fish burger	Freezing	LDPE and corrugated board	LDPE, wood pallet
				1 kg of loins	Chilling	HDPE tray and plastic film	Expanded polystyrene, LDPE film
21	Svanes et al., 2011b	Cod	Fisheries	1 kg wetpack	Freezing	Polyamide and polyethylene	Polyethylene film, wood pallet, carton
				1 kg fish-burger	Chilling	LDPE and corrugated board	LDPE, wood pallet
				1 kg loins	Freezing	HDPE tray and plastic film	Expanded polystyrene, LDPE film
22	Tamburini et al., 2019	Oysters	Aquaculture	1 kg of commercial fresh oysters at farm gate	Chilling	Wooden baskets	-
23	van Putten et al., 2016	Lobster	Fisheries	1 kg live Southern rock lobster	Chilling	Styrofoam boxes	-
				1 kg live Tropical rock lobsters	Chilling	Styrofoam boxes	
				350 g Tropical rock lobster	Freezing	Waxed cardboard box	
24	Vázquez-Rowe et al., 2011	Hake	Fisheries	500 g of raw gutted fresh hake fillet at the household	Chilling	HDPE	Polystyrene, fish boxes
25	Vázquez-Rowe, Moreira, et al., 2012	Octopus	Fisheries	24 kg cartoon of frozen octopus	Freezing	Corrugated board and polyethylene	Pallets
26	Vázquez-Rowe et al., 2013	Hake	Fisheries	324 g of sticks	Freezing	Cardboard box, polyethylene, and retractable polyolefin	-
27	Vázquez-Rowe, Villanueva-Rey, Moreira, et al., 2013	Hake	Fisheries	324 g of frozen fish sticks of Patagonian grenadier	Freezing	Cardboard and polyethylene boxes	-
28	Vázquez-Rowe et al., 2014	Sardines	Fisheries	85 g of protein supplied by one can of sardines in olive oil	Canning	Tinplate can	Cardboard, Corrugated board, plastic film
29	Ziegler & Valentinsson, 2008	Lobster	Fisheries	300 g of Norway lobster tails	Other (cooking)	Disposable bucket of polypropylene	-
30	Ziegler et al., 2003	Cod	Fisheries	400 g frozen cod fillets	Freezing	LDPE and laminated cardboard	LDPE
31	Ziegler et al., 2011	Shrimp	Fisheries	1 kg of shrimp and packaging material at the point of import to Europe	Freezing, industrial	Cardboard	-
					Freezing, artisanal	Cardboard	
32	Zufia & Arana, 2008	Tuna	Fisheries	2 kg tray of pasteurized tuna with tomato	Other (cooking - pasteurizing)	Vacuum-packaged made of HDPE,	-

						polyethylene film, and polyamide nylon	

According to the post-harvest processing, canned seafood studies (n=17) present a small variety of seafood products, including anchovies, mussels, sardines, and tuna. Chilled products (n=12) are associated with hake, lobsters, oysters, trout, and salmon, while frozen products (n=17) are linked with cod, hake, octopus, prawns, shrimps, tilapia, and shrimps. The category “Others” (n=4), related to processing operations like cooking and a combination of freezing and modified atmosphere packaging (MAP) or chilled and pasteurized, presented products with tuna, lobsters, catfish, and other fish species not specified.

Two main primary packaging materials – tinplate and aluminum – were associated to canned seafood products, although other types of packaging formats are considered (e.g. plastic from a retort pouch and glass). Chilled products were associated with primary packaging made of paper, plastic and one with wood (used for fresh oysters’ package), while frozen products were only linked with paper and plastic. The category “Others” included only plastic materials. All products analyzed included primary packaging but 22 out of the 50 products evaluated presented information related to secondary packaging. Secondary packaging consists usually of cardboard boxes, but plastic films, expanded polystyrene boxes and pallets were also considered. Data related to the geographic scope, system boundaries, and LCIA methods can be accessed in Table S1 of SI. More than half of the articles have the geographical scope in Europe (56%), the remaining being related to the 5 main continents left.

The articles used different LCIA methods but CML, a midpoint-oriented method (Heijungs et al., 1992), is the most used LCIA method followed by ReCiPe, a method which comprises harmonized category indicators at the midpoint and the endpoint level (Goedkoop et al., 2013). Likewise, the functional units are based on different measurements as, for example, weight for the whole product, only edible product (Almeida et al., 2015) or protein quantity (Vázquez-Rowe et al., 2014). Therefore, the impact assessment results are not strictly comparable in absolute terms, but they are useful for further examining patterns on the environmental assessment of packaging on seafood products both for qualitative and quantitative analysis.

3.1 Qualitative analysis of packaging in seafood LCA studies

Table 2 summarizes results of the packaging qualitative analysis. Overall, it was found that packaging was not often included in the eight life cycle steps analyzed and is more considered in direct than indirect impacts, i.e. primary packaging material (100% of articles), secondary packaging material (44% of articles) and packaging end-of-life (31% of articles). For the five indirect impacts considered, packaging was considered in 34% for preparation by households, 13% for both transport from producer to retail and storage, 3% for emerging innovations and not considered for FLW. Sensitivity analyses were carried out only for the primary packaging material (direct impact) in 7 out of 32 articles, and in one article for the transport from producer to retail life cycle step (indirect impact). Recommendations were found for all life cycle steps, except storage and preparation by households.

Primary packaging material was the life cycle step that presented the highest number of sensitivity analysis (22% of articles) and recommendations (38% of articles). Most of the recommendations were related to the substitution of packaging material for canning and curing products (n=8), as for example, to use plastic or glass instead of tinplate and aluminum. Replacing tinplate by aluminum, as proposed by Avadí et al. (2015) for canned tuna would reduce the environmental impact by 63% at the endpoint level for the 3 Areas of Protection (human health, resources, and ecosystems) (ReCiPe method). In the case of canned sardine products, the same replacement was proposed by Almeida et al. (2015) and led to a reduction of 56% of the climate change. Hospido et al. (2006) suggested that the use of plastic bags instead of tinplate cans for tuna packaging would represent a reduction up to 50% in terms of climate change and acidification for the overall assessment of the product. Likewise, according to Almeida et al. (2015) and Laso et al. (2018), plastic seems to be the best option because it shows the lowest values for all the impact categories studied. Apart from the use of plastic formats, Vázquez-Rowe et al. (2014) proposed glass jars, which have a greater potential depending on the number of times that glass is reused by consumers prior to the recycling process. However, these recommendations raise the argument that packaging material substitution implies a change in the final appearance of the product which may affect consumers acceptance (Hospido et al., 2006; Laso et al., 2017) and imply considerable changes in machinery linked to industrial logistics. Other recommendations of primary packaging to decrease the environmental impacts were related to changing packaging design (n=3), namely the size by using larger cans for canned products (Avadí et al., 2014, 2015) or form by redesigning the package (Zufia & Arana, 2008). Two articles also recommended to reduce the amount and consequently the weight of the material used in the package (Nhu et al., 2015; Pardo & Zufía, 2012).

The inclusion of the secondary packaging material was found in 44% of the articles analyzed, but only one issued a recommendation specifically related to this type of packaging. Pardo & Zufía (2012) studied food-preservation technologies, suggesting the modification of both primary and secondary packaging as the best opportunity to reduce the impact assessment of the final product within different food preservation systems.

Table 2. Results of the qualitative analysis related to the packaging environmental impacts, including packaging recommendations for improving the environmental performance of packaging identified in seafood LCA reviewed articles.

Life cycle step	**Packaging included in the scope of LCA studies**	**Sensitivity analysis in LCA studies**	**Recommendations in LCA studies**	**Type of recommendation (# - article number in table 1)**
Primary packaging material (direct impact)	100% (n=32)	22% (n=7)	38% (n=12)	▪ Substitution of tinplate or aluminum by other packaging non-metal materials such as plastic or glass for canned products (articles #1, #3, #7, #8, #12, #13, #28). ▪ Substitution of tinplate or aluminum by glass container for cured products (article #2). ▪ Use larger cans for canning products (articles #2, #3). ▪ Redesign of the package with regard to form and composition for pre-cooked products (article #32). ▪ Substitution of plastic boxes with laminated cardboard to transport frozen products (article #21). ▪ Reduce weight in the primary package (articles #15, #16).
Secondary packaging material (direct impact)	44% (n=14)	0% (n=0)	3% (n=1)	Modify secondary packaging to reduce the impact related to food preservation methods (article #16)
Food loss and waste (indirect)	0% (n=0)	0% (n=0)	6% (n=2)	▪ Canned products can lower the risk of food losses (article #1). ▪ Higher data quality regarding food waste in post-landing activities is needed (article #28).
Transport from producer to retail (indirect impact)	13% (n=4)	3% (n=1)	3% (n=1)	Substitution of boxes material to transport frozen products with less weight (article #21).
Storage (indirect impact)	13% (n=4)	0% (n=0)	0% (n=0)	-
Preparation by households (indirect impact)	34% (n=11)	0% (n=0)	0% (n=0)	-
Packaging end-of-life (direct impact)	31% (n=10)	0% (n=0)	9% (n=3)	▪ Avoid packaging waste because recycling/reuse of packaging materials reduces burden via substitution of virgin materials (articles #15, #16). ▪ Each additional unit of material recycled would displace an equivalent quantity of the current mix of virgin (article #12).

Emergent innovations (indirect impact)	3% (n=1)	0% (n=0)	3% (n=1)	The application of different preservation technologies and development of novel products imply the selection of different packaging and it must be carefully considered since the type of packaging may play an important role when aiming to improve sustainability of food preservation methods (article #16).

Packaging was not associated with FLW among the 32 articles analyzed, but two recommendations were found. One article suggested that higher data quality is needed regarding food losses in post-landing activities (Vázquez-Rowe et al., 2014), where packaging has a function also. The other article pointed out that canning has a post-harvesting process that contributes to lower the risk of food losses along the supply chain (Almeida et al., 2015), in part due to its long shelf-life related to packaging preservation features.

Packaging was considered both in the transport and storage stages in 13% of the articles analyzed, but recommendations were found only to transport and in one article. Svanes et al. (2011b) suggested to substitute plastic boxes with laminated cardboard to transport frozen products to alleviate the weight carried. The effect of such a replacement could be a reduction of 0.7-1.1% of total climate change of the seafood product analyzed.

Preparation by households is the life cycle step from indirect environmental impacts where packaging was most considered, being found in 34% of articles analyzed. However, no recommendations to decrease this indirect impact have been found in literature.

The end-of-life step included packaging in the environmental impact in 31% of the articles. Recommendations found in three articles denoted the importance of recycling packaging materials to reduce the burden via substitution of virgin materials. However, recycling is considered in different ways, depending on the article, thus introducing variability to results. For instance, in the case of the anchovy industry it is assumed that 37% of aluminum cans and 84% of cardboard boxes were recycled (Laso et al., 2018). In the case of mussels, 64 % of tinplate cans and 62 % of cardboards were considered for recycling separately, where the rest is disposed as general waste (Iribarren, Moreira, et al., 2010b).

Emerging innovations and its relation to packaging have been poorly explored in seafood LCA studies. Only Pardo and Zufía (2012) mentioned that application of different preservation technologies and the development of novel products imply the selection of different packaging options. However, innovations must be carefully considered, especially when aiming to improve the sustainability of the preservation method, since the type of packaging may play an important role.

3.2 Quantitative analysis of packaging in seafood LCA studies

The contribution of packaging to the final weight of seafood products was assessed according to the type of post-harvest processing (Figure 2) and main packaging material (Figure 3). For frozen, chilled and pre-cooked products, packaging has a relatively low contribution to weight, representing less than 6% and ranging between 0 to 12%. Yet, for canned products, the weight importance of packaging represents on average 27% seafood product weight, ranging between 11 to 53%. The high variability obtained comes principally from differences between metal and glass materials used for canning. Glass is the packaging material with the highest contribution to the product weight, even if found in only one product with 53% contribution (Laso et al. 2017). It is followed by tinplate, and aluminum, with 28% and 22% on average respectively. Packaging made by plastic and paper presented the lowest contribution to the product weight with 6% on average. Wood represented around 11% of product weight, but it was included only in one study related to wooden baskets from oysters (Tamburini et al., 2019). The package size or volume was not accessible and it was not possible to confirm if smaller package sizes led to a higher packaging contribution than larger ones. However, size/volume would not give further information since weight gives the specific amount of each material used in each package.

The relative contribution of packaging to climate change impact in the life cycle of seafood products was analyzed according to the type of post-harvesting operations (Figure 4) and packaging main material (Figure 5). For canned products, packaging contribution to climate change impact is significant, representing on average 42% of the product life cycle and ranging between 6% and 89%. Canning packaging usually results in more than 1 kg CO_2 eq/kg of food (Table 3). Among the canning packaging materials, both tinplate and aluminum, presented almost the same order of contribution, ranging between 6-89% and 10-83% respectively, which can be explained by the high environmental impacts associated with the energy requirements for extraction, processing and transport of these type of materials (Vázquez-Rowe et al., 2014). The high variability found in the contribution of canned packaging to the overall impacts of the products might be explained by three factors. Firstly, the high contribution of packaging to the product's weight, as explained above. Secondly, the impact from seafood production, resulting in different relative contribution from packaging. For instance, climate change impact specifically for sardine from Portuguese purse seiners was almost half of that from Galicia (Almeida et al., 2015). Thirdly, can production includes different operations and its associated background data might be modelled in different ways, considering different data sources or assuming country-specific recycling rates. For instance, sealing compounds, coatings or substances used in the inner cans are difficult to consider or are not included in the studies (e.g. Avadí et al., 2014). Furthermore, metal cans are modelled from metal sheets and a margin for production scraps plus average metalwork is necessary to be included, challenging the ecoinvent paradigm of modelling all products in bulk (Avadí et al., 2020). To overcome such variability further experimental research is required to optimize the environmental impact on the industrial canned processing and to confirm to which extent factors here identified significantly affect the assessment of results.

Table 3. Results of the quantitate analysis of the packaging contribution to products' weight and climate change (CC) of the product life cycle (* Type of post-harvest processing: CA – canning; F – Freezing; CH – Chilling; CO – Cooking)

#	Type *	Packaging material	Packaging weight (kg)	Product weight including packaging (kg)	Contribution of packaging to product weight (%)	CC for FU (kgCO2eq/kg of food)	CC of packaging (kgCO2eq/kg of food)	Contribution of packaging to CC of product life cycle (%)
1	CA	Aluminum	0.4	1.4	30.6%	7.7	5.5	71.8%
2.1	CA	Tinplate	0.1	1.1	11.5%	1.9	1.2	65.0%
2.2	CA	Tinplate	0.2	1.2	17.4%	3.7	2.1	57.9%
3.1	CA	Tinplate	10590814.0	31982814.0	33.1%	8.0	1.6	20.5%
3.2	CA	Plastic	561667.6	3091667.6	18.2%	4.1	0.3	7.7%
3.3	F	Plastic	206552.0	3074552.0	6.7%	3.8	0.0	0.2%
4	CH	Paper	100.0	1100.0	9.1%	-	0.2	2.5%
5	CH	Plastic	0.0	1.0	2.9%	31.0	1.0	3.1%
6	F	Paper	0.0	1.0	2.9%	7.2	0.1	0.7%
7	CA	Tinplate	447.4	1107.4	40.4%	8.3	1.0	12.1%
8	CA	Tinplate	93.7	342.7	27.3%	17.8	15.9	89.2%
9	CA	Tinplate	108.7	386.5	28.1%	1.8	0.2	9.2%
11.1	CA	Tinplate	0.8	1.8	43.2%	9.8	0.6	5.8%
11.2	CH	Plastic	3.8	1003.8	0.4%	13.9	-	0.5%

11.3	F	Paper	0.1	1.1	5.7%	9.5	-	0.5%
12.1	CA	Aluminum	0.1	0.7	16.1%	-	-	83.0%
12.2	CA	Tinplate	0.2	0.8	22.2%	-	-	56.0%
12.3	CA	Glass	0.7	1.3	52.8%	-	-	41.0%
12.4	CA	Plastic	0.1	0.7	15.4%	-	-	40.0%
13.1	CA	Aluminum	118.3	743.3	15.9%	-	-	10.0%
13.2	CA	Aluminum	299.5	1116.5	26.8%	-	-	20.0%
16	CO	Plastic	51.5	1051.5	4.9%	-	0.1	-
17	CH	Plastic	0.0	1.0	2.1%	13.2	-	0.5%
18	F	Paper	132.5	1132.5	11.7%	2.0	0.1	3.7%
19	CH	Plastic	-	-	-	5.4	0.0	13.2%
20.1	F	Plastic	0.0	0.4	3.7%	3.6	0.2	4.5%
20.2	F	Plastic	0.0	0.4	7.9%	3.7	0.2	4.8%
20.3	F	Plastic	0.3	5.3	6.1%	1.8	0.1	5.6%
20.4	CH	Plastic	0.1	2.1	5.4%	7.6	0.3	4.0%
22	CH	Wood	0.1	1.1	11.1%	1.9	0.0	1.0%
23.1	CH	Plastic	0.0	1.0	2.9%	15.8	0.2	1.0%
23.2	CH	Plastic	0.0	1.0	2.9%	9.3	0.0	0.2%
23.3	F	Paper	0.0	0.4	3.8%	3.2	0.0	0.2%
24	CH	Plastic	1.5	501.5	0.3%	3.8	0.8	10.9%
25	F	Paper	393.8	24393.8	1.6%	7.8	0.0	0.3%
26	F	Paper	25.8	349.3	7.4%	2.2	0.1	4.6%
28	CA	Tinplate	-	-	-	3.4	2.6	77.4%
29	CO	Plastic	0.8	8.8	8.6%	11.1	0.5	4.9%
30	F	Plastic	81400.0	3959400.0	2.1%	7275.0	19.5	0.3%
31.1	F	Paper	-	-	-	37.0	2.8	7.5%

31.2	F	Paper	-	-	-	8.0	2.8	35.0%
32	CO	Plastic	80.2	2000.0	4.0%	-	-	-

Packaging contribution from freezing, chilling and other types of seafood products' processing is on average less than 5% of climate change impact for the seafood life cycle, and usually results in less than 1 kg CO_2 eq/kg of food (Table S2 of SI). Regarding the type of materials used in the packaging, it was not observed a major difference among paper, plastic or wood. However, packaging of one frozen product made of paper represented around 35% of climate change impact. It corresponds to 1 kg of shrimp caught by an artisanal fishery (Ziegler et al., 2011), which is associated to a low climate change impact production method (8 kg CO_2 eq/kg of food) and, as a consequence, the packaging relative contribution was enlarged.

Most proposals for seafood LCA improvements are mainly focused on reducing energy or fuel consumption. However, for the canning industry, even though the thermal processes of cooking and sterilization are an important part of the process, results showed that can production is the most important contributor to climate change impact. Several authors reported the environmental impacts of packaging in canned seafood products, such as tuna (Avadí et al., 2015; Hospido et al., 2006), sardine (Almeida et al., 2015; Vázquez-Rowe et al., 2014), mussels (Iribarren, Hospido, et al., 2010; Iribarren, Moreira, et al., 2010a), and anchovy (Avadí et al., 2014; Laso et al., 2018). Tinplate was the most common material described in the selected articles for canning products, whereas aluminum was only identified for canned Portuguese sardine (Almeida et al., 2015) and Cantabrian anchovy (Laso et al., 2018). Other options such as glass and plastic were included in only one study (Laso et al., 2017b) and further LCA studies with foreground data related to these packaging materials are needed to confirm patterns here described.

Regarding frozen products, cardboard combined with plastics have been widely applied for primary packaging. For cooked products, the final preparation has a high influence on the packaging choice, since some products are microwaved and require plastic packaging. Nevertheless, due to the low contribution from these materials (paper and plastic), the efforts to reduce environmental impacts from packaging of frozen and cooked seafood products should be more focused on indirect impacts, such as increasing the potential to reduce seafood loss and waste.

3.3 Main challenges to improve seafood packaging sustainability – food waste, circular economy and innovation

Food waste is highly influenced by primary packaging design and materials (de la Caba et al., 2019; Heller et al., 2019). For example, packaging design influences FLW at the consumer-level if the packaging is not easy to empty and food remains attached to the packaging surface (Williams et al., 2012). Also, if packaging has inappropriate opening devices it can cause food spill (Duizer et al., 2009). Another cause of FLW related with packaging is the existence of several date labelling schemes that vary in terminology, which are largely misunderstood by consumers (Heller et al., 2019). Some LCA studies for food other than seafood demonstrated the relevance of considering the impact of packaging on FLW (e.g. Heller et al., 2019; Wikström et al., 2016; Williams & Wikström, 2011). Notwithstanding, although some LCA studies on seafood products evaluated FLW (Vázquez-Rowe et al., 2011, 2014), none of them assessed the influence of packaging on FLW. Due to high environmental impact from seafood production, there is a high potential of improvements by reducing FLW along the supply chain, for example, by improving storage conditions to avoid secondary and primary packaging damage (Molina-Besch, 2016; Williams et al., 2012). Or at the household, where the climate impact associated with the wasted food part (meat, fish and egg together) can contribute more than packaging materials, 18% against 2% respectively, being the rest related to the consumed food part (80%) (Verghese et al., 2014). Therefore, further LCA studies should estimate to which extent each type packaging can affect seafood waste and how improvements in materials or design might reduce associated impacts.

Alternatives to some plastic-based packaging are one of the challenges of the seafood industry. For instance, polystyrene, a single-polymer foam globally used both for packaging and insulation purposes, is widely used by the fish processing industry. It is an efficient way of transporting fish, but it has environmental and climate costs throughout its production, use and disposal and is a major component of terrestrial and marine litter (FIDRA, 2020). For this reason, packaging fate plays a key role in the environmental burden of seafood packaging. In fact, impacts related to plastic leakage and subsequent fate of the polymers and/or their products once these have been released to the marine environment are not considered in LCA and can result in underestimated impacts associated to plastic-based packaging. More knowledge is required on effects from the hazardousness of the substances in the microplastics (e.g. residual monomer content, additive content, ability to transport hazardous substances), and on the usage and characteristics of the macroplastics (e.g. plastics types, shapes, colours most likely to lead to cases of entanglement and ingestion) (Ryberg et al., 2018). Progresses to include plastic leakages both at the inventory and impact assessment steps of LCA will be an important improvement to enable a fair comparison between plastic and its substitutes (Verones et al., 2020).

Recycling is a common end-of-life route considered in LCA studies and for some materials (e.g. aluminum, glass, paper, plastics) it provides more environmental benefits than other waste management options (Michaud et al., 2010). Avoided GHG emissions from the recovery of materials is highest for aluminum cans, with -8143 kg CO_2e per tonne of material collected for recycling, and large for mixed plastics and mixed glasses, with emission factors of -1024 and -314 kg CO_2e per tonne respectively (Turner et al., 2015). However, benefits from recycling are mainly achieved by avoiding production of virgin materials, which is not the case so far since packaging materials entering to recycling, for example in Europe, represent between 57% for paper and 19% for plastic (Tallentire & Steubing, 2020). The current low capacity for the treatment of recycled materials may lead to higher GHGs emissions, through increased transportation distances and less efficient treatment of the wasted material (Spierling et al., 2020; Wojnowska-Baryła et al., 2020). This may be ameliorated through facilities in close proximity, which is not the case in Europe for plastics, where large quantities are exported to other countries (Frei & Vazquez-Brust, 2020). Also, to maintain the effectiveness of mechanical or chemical recycling of plastic, the separation of different plastic types is required. For example, bio-based products need to be separated from plastic to be composted with biowaste, another option for recycling (Wojnowska-Baryła et al., 2020). Due to limitations of current waste management systems, whilst recycling is an important part of the circular economy, extending the lifetime or phasing out products is also imperative (Tallentire & Steubing, 2020). Therefore, apart from recycling, other end-of-life forms as reuse, energy recovery (e.g. for types of plastic packaging that cannot be recycled) or disposal (e.g. landfill, anaerobic digestion compost) should be assessed (Spierling et al., 2020).

Waste streams from the seafood sector can also be part of the transition from a linear to a circular economy (Ruiz-Salmón et al., 2020). Bio-based materials such as fish trimmings, crustacean and mollusk shells are viable candidates in the displacement of conventional fossil fuel derived packaging material (Barros et al., 2009; de la Caba et al., 2019). Recent literature has demonstrated how fish trimmings valorized as gelatin and crustacean shells as chitosan can contribute to the circular economy as active packaging (de la Caba et al., 2019). However, as valorization of wastes and the transition to a circular economy becomes more a common procedure, it is important that seafood derived feedstocks do not repeat errors of other bio-based materials and adhere to recommendations from the most recent state of the art. Spierling et al. (2020) highlight the lack of diversity in bio-based plastics and a lack of detail and consideration of end-of-life options. An increased research effort has been made to address methodological gaps in bio-materials assessment, primarily in the composting or landfill where bio-plastics have higher greenhouse gas emissions than fossil fuel derived ones (de la Caba et al., 2019; Ingrao et al., 2015).

In this sense, chitosan films and chitosan-based nanocomposites made from waste materials have been presented as an alternative for plastic in seafood packaging (de la Caba et al., 2019; Kakaei & Shahbazi, 2016; Qiu et al., 2014). Chitosan presents considerable advantages when compared to other bioplastics for which the raw material requires a dedicated industry or redirection from human food chains (de la Caba et al., 2019). It is biodegradable, provides antimicrobial activity and offers film-forming properties making it an alternative to synthetic plastics polymers. Research showed an enhanced quality of the product, extension of its shelf life, and benefits from adding nanomaterials to chitosan that extend the shelf life and prevent spoilage. As an example, chitosan film with grape seed extract and carvacrol microcapsules was tested on salmon (*Salmo salar*) and refrigerated shelf-life was extended by 4–7 days (Alves et al., 2018). Due to its relevance, studies that point out chitosan's environmental cost and market accessibility would be important to promote the development of this seafood waste bio-material that can foster a successful transition to a circular economy.

A reform or reduction of packaging has been successfully proposed with nanotechnology, to develop and design novel food packaging systems that also showed reduced microbial growth (Kour et al., 2015). Studies carried out on sea bream fillets reported an extension of shelf-life using skin packaging in combination with super chilling storage (Duran-Montgé et al., 2015). Many researchers outlined how innovative techniques such as active packaging and intelligent packaging systems may contribute to prolong shelf life, enable effective cold chain management and food waste reduction (Gokoglu, 2020; Janjarasskul & Suppakul, 2018; Tsironi & Taoukis, 2018). Packaging is among the opportunities to future proofing in the seafood industry and its potential for market and product sustainability can accelerate innovations. Consequently, LCA should play a key role in the development of any novel packaging materials or waste valorization strategies.

4. CONCLUSIONS AND RECOMMENDATIONS

Packaging is essential to guarantee food quality and minimize waste and other associated potential environmental impacts. However, unpackaged products can be less expensive and signal freshness or confidence in their origin. Optimizing all these (sometimes opposing) variables is challenging in food packaging. In the case of seafood, packaging has demonstrated to significantly contribute to the total environmental impact along the whole supply chain independently of the origin of species, aquaculture type or fishing gear. Therefore, the sum of the potential environmental impacts of packaging production and further stages related to packaging - transport, storage, food preparation, food wasted, reuse or disposal - cannot be neglected.

Seafood LCAs focus mainly on the direct environmental impact coming from the packaging materials, to which some articles develop sensitivity analysis related to materials substitution. The most common recommendations to reduce this impact are either to reduce packaging volume or weight or to substitute materials. Direct impacts related to packaging end-of-life have also been evaluated, and the most common recommendation is to increase recycling rates. However, recycling depends on many factors, among them, the recyclability rate of materials and infrastructure or facilities capable of recycling these materials in close proximity. Besides, independently of how much materials are recycled, if packaging production and its disposal do not decrease, part of the environmental burden will continue. For these reasons, recovery rates and other packaging end-of-life forms such as reuse and different disposal choices of packaging (e.g. anaerobic digestion compost) should also be considered.

Apart from the household preparation, other indirect environmental impacts derived from packaging related to transport, storage requirements, FLW avoidance or the application of packaging innovations are often under-considered, but could lead to a reduction of the overall environmental impact of seafood products. Avoidance of seafood waste throughout the supply chain is especially relevant due to the spoilage potential of seafood compared to other food products. Therefore, LCA studies should explore further, the extent to which packaging can affect seafood waste and how packaging materials and design options can mitigate these impacts throughout the supply chain.

The nature of both the post-harvesting processing and the type of material has a great influence on the packaging contribution to the total environmental impact of the product. Packaging from canned products has a significant environmental contribution and the highest in comparison to other type of products. However, canned seafood may present other benefits like, for example, they have a long shelf life and do not require energy for conservation. These aspects should be further investigated in a more holistic environmental assessment of seafood products. The packaging material production is more relevant to aluminum, tinplate and glass than for plastic and paper. Therefore, it is essential to accurately include these materials and their associated operations in processing inventories (e.g. metal cans modelling). The mass ratio of the packaging is not very important with the exception of glass, but a reduction of weight of packaging with respect to the food product would be an advantage.

Within the articles analyzed, it was noted that a limited number of LCA seafood studies include packaging and, in some cases, inventory data is not presented in detail or contribution to the total impact assessment is unclear. Therefore, detailed information about packaging would be relevant to further understand whether differences between seafood LCA studies are related to impacts from packaging materials production or the form packaging is accounted. More LCA studies are needed to consistently map seafood products including its packaging among complete supply chains.

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7. REFERENCES

Abejón, R., Bala, A., Vázquez-Rowe, I., Aldaco, R., & Fullana-i-Palmer, P. (2020). When plastic packaging should be preferred: Life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. *Resources, Conservation and Recycling*, *155*(December 2019), 104666. https://doi.org/10.1016/j.resconrec.2019.104666

Almeida, C., Vaz, S., & Ziegler, F. (2015). Environmental Life Cycle Assessment of a Canned Sardine Product from Portugal. *Journal of Industrial Ecology*, *19*(4), 607–617. https://doi.org/10.1111/jiec.12219

Alves, V. L. C. D., Rico, B. P. M., Cruz, R. M. S., Vicente, A. A., Khmelinskii, I., & Vieira, M. C. (2018). Preparation and characterization of a chitosan film with grape seed extract-carvacrol microcapsules and its effect on the shelf-life of refrigerated Salmon (Salmo salar). *LWT*, *89*, 525–534. https://doi.org/10.1016/j.lwt.2017.11.013

Avadí, A., Bolaños, C., Sandoval, I., & Ycaza, C. (2015). Life cycle assessment of Ecuadorian processed tuna. *International Journal of Life Cycle Assessment*, *20*(10), 1415–1428. https://doi.org/10.1007/s11367-015-0943-2

Avadí, A., Fréon, P., & Quispe, I. (2014). Environmental assessment of Peruvian anchoveta food products: Is less refined better? *International Journal of Life Cycle Assessment*, *19*(6), 1276–1293. https://doi.org/10.1007/s11367-014-0737-y

Avadí, A., Vázquez-Rowe, I., Symeonidis, A., & Moreno-Ruiz, E. (2020). First series of seafood datasets in ecoinvent: setting the pace for future development. *The International Journal of Life Cycle Assessment*, *25*(7), 1333–1342. https://doi.org/10.1007/s11367-019-01659-x

Barros, M. C., Magán, A., Valiño, S., Bello, P. M., Casares, J. J., & Blanco, J. M. (2009). Identification of best available techniques in the seafood industry: a case study. *Journal of Cleaner Production*, *17*(3), 391–399. https://doi.org/10.1016/j.jclepro.2008.08.012

Bohnes, F. A., Hauschild, M. Z., Schlundt, J., & Laurent, A. (2019). Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development. *Reviews in Aquaculture*, *11*(4), 1061–1079. https://doi.org/10.1111/raq.12280

de la Caba, K., Guerrero, P., Trung, T. S., Cruz-Romero, M., Kerry, J. P., Fluhr, J., Maurer, M., Kruijssen, F., Albalat, A., Bunting, S., Burt, S., Little, D., & Newton, R. (2019). From seafood waste to active seafood packaging: An emerging opportunity of the circular economy. In *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.09.164

Del Borghi, A., Moreschi, L., & Gallo, M. (2020). Life cycle assessment in the food industry. In *The Interaction of Food Industry and Environment* (pp. 63–118). Elsevier. https://doi.org/10.1016/B978-0-12-816449-5.00003-5

Denham, F. C., Howieson, J. R., Solah, V. A., & Biswas, W. K. (2015). Environmental supply chain management in the seafood industry: Past, present and future approaches. *Journal of Cleaner Production*, *90*, 82–90. https://doi.org/10.1016/j.jclepro.2014.11.079

Driscoll, J., Boyd, C., & Tyedmers, P. (2015). Life cycle assessment of the Maine and southwest Nova Scotia lobster industries. *Fisheries Research*, *172*, 385–400. https://doi.org/10.1016/j.fishres.2015.08.007

Duizer, L. M., Robertson, T., & Han, J. (2009). Requirements for packaging from an ageing consumer's perspective. *Packaging Technology and Science*, *22*(4), 187–197. https://doi.org/10.1002/pts.834

Duran-Montgé, P., Permanyer, M., & Belletti, N. (2015). Refrigerated or Superchilled Skin-Packed Sea Bream (S parus aurata) Compared with Traditional Unpacked Storage on Ice with Regard to Physicochemical, Microbial and Sensory Attributes. *Journal of Food Processing and Preservation*, *39*(6), 1278–1286. https://doi.org/10.1111/jfpp.12346

Farmery, A., Gardner, C., Green, B. S., & Jennings, S. (2014). Managing fisheries for environmental performance: The effects of marine resource decision-making on the footprint of seafood. *Journal of Cleaner Production*, *64*, 368–376. https://doi.org/10.1016/j.jclepro.2013.10.016

Farmery, A., Gardner, C., Green, B. S., Jennings, S., & Watson, R. (2015). Life cycle assessment of wild capture prawns: Expanding sustainability considerations in the Australian Northern Prawn Fishery. *Journal of Cleaner Production*, *87*(1), 96–104. https://doi.org/10.1016/j.jclepro.2014.10.063

FIDRA. (2020). *Polystyrene pollution and practical solutions*. https://www.fidra.org.uk/what-problems-does-polystyrene-present/

Flanigan, L., Frischknecht, R., & Montalbo, T. (2013). *An Analysis of Life Cycle Assessment in Packaging for Food & Beverage Applications*.

Frei, R., & Vazquez-Brust, D. (2020). *What happens to the plastic you recycle? Researchers lift the lid*. https://theconversation.com/what-happens-to-the-plastic-you-recycle-researchers-lift-the-lid-142831

Fréon, P., Avadí, A., Vinatea Chavez, R. A., & Iriarte Ahón, F. (2014). Life cycle assessment of the Peruvian industrial anchoveta fleet: Boundary setting in life cycle inventory analyses of complex and plural means of production. *International Journal of Life Cycle Assessment*, *19*(5), 1068–1086. https://doi.org/10.1007/s11367-014-0716-3

Goedkoop, M., Heijungs, R., De Schryver, A., Struijs, J., & van Zelm, R. (2013). *ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, Report I: Characterisation*. https://www.rivm.nl/en/life-cycle-assessment-lca/downloads

Gokoglu, N. (2020). Innovations in Seafood Packaging Technologies: A Review. *Food Reviews International*, *36*(4), 340–366. https://doi.org/10.1080/87559129.2019.1649689

Gustavsson, J., Cederberg, C., & Sonesson, U. (2011). Global Food Losses and Food Waste. In *Unep* (Issue May). https://doi.org/10.1098/rstb.2010.0126

Heijungs, R. ., Guinée, J. B. ., Huppes, G. ., Lankreijer, R. M. ., Udo de Haes, H. A. ., Wegener Sleeswijk, A.; Ansems, A. M. M. ., Eggels, P. G. ., Duin, R. van;, & Goede, H. P. de. (1992). *Environmental life cycle assessment of products: guide and backgrounds (Part 1)*. https://hdl.handle.net/1887/8061

Heller, M. C., Selke, S. E. M., & Keoleian, G. A. (2019). Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments. In *Journal of Industrial Ecology* (Vol. 23, Issue 2, pp. 480–495). https://doi.org/10.1111/jiec.12743

Hospido, A., Vazquez, M. E., Cuevas, A., Feijoo, G., & Moreira, M. T. (2006). Environmental assessment of canned tuna manufacture with a life-cycle perspective. *Resources, Conservation and Recycling*, *47*(1), 56–72. https://doi.org/10.1016/j.resconrec.2005.10.003

Ingrao, C., Tricase, C., Cholewa-Wójcik, A., Kawecka, A., Rana, R., & Siracusa, V. (2015). Polylactic acid trays for fresh-food packaging: A Carbon Footprint assessment. *Science of The Total Environment*, *537*, 385–398. https://doi.org/10.1016/j.scitotenv.2015.08.023

Iribarren, D., Hospido, A., Moreira, M. T., & Feijoo, G. (2010). Carbon footprint of canned mussels from a business-to-consumer approach. A starting point for mussel processors and policy makers. *Environmental Science and Policy*, *13*(6), 509–521. https://doi.org/10.1016/j.envsci.2010.05.003

Iribarren, D., Moreira, M. T., & Feijoo, G. (2010a). Implementing by-product management into the life cycle assessment of the mussel sector. *Resources, Conservation and Recycling*, *54*(12), 1219–1230. https://doi.org/10.1016/j.resconrec.2010.03.017

Iribarren, D., Moreira, M. T., & Feijoo, G. (2010b). Life Cycle Assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain). *Resources, Conservation and Recycling*, *55*(2), 106–117. https://doi.org/10.1016/j.resconrec.2010.08.001

Iribarren, D., Moreira, M. T., & Feijoo, G. (2010c). Revisiting the Life Cycle Assessment of mussels from a sectorial perspective. *Journal of Cleaner Production*, *18*(2), 101–111. https://doi.org/10.1016/j.jclepro.2009.10.009

ISO. (2016). *Packaging — Vocabulary — Part 1: General terms. ISO21067-1*. International Organization for Standardization.

Janjarasskul, T., & Suppakul, P. (2018). Active and intelligent packaging: The indication of quality and safety. *Critical Reviews in Food Science and Nutrition*, *58*(5), 808–831. https://doi.org/10.1080/10408398.2016.1225278

Kakaei, S., & Shahbazi, Y. (2016). Effect of chitosan-gelatin film incorporated with ethanolic red grape seed extract and Ziziphora clinopodioides essential oil on survival of Listeria monocytogenes and chemical, microbial and sensory properties of minced trout fillet. *LWT - Food Science and Technology*, *72*, 432–438. https://doi.org/10.1016/j.lwt.2016.05.021

Kour, H., Malik, A. A., Ahmad, N., Wani, T. A., Kaul, R. K., & Bhat, A. (2015). Nanotechnology –New Lifeline For Food Industry. *Critical Reviews in Food Science and Nutrition*, 00–00. https://doi.org/10.1080/10408398.2013.802662

Laso, J., Margallo, M., Fullana, P., Bala, A., Gazulla, C., Irabien, Á., & Aldaco, R. (2017a). When product diversification influences life cycle impact assessment: A case study of canned anchovy. *Science of The Total Environment*, *581–582*, 629–639. https://doi.org/10.1016/j.scitotenv.2016.12.173

Laso, J., Margallo, M., Fullana, P., Bala, A., Gazulla, C., Irabien, Á., & Aldaco, R. (2017b). When product diversification influences life cycle impact assessment: A case study of canned anchovy. *Science of The Total Environment*, *581–582*, 629–639. https://doi.org/10.1016/j.scitotenv.2016.12.173

Laso, J., Margallo, M., Serrano, M., Vázquez-Rowe, I., Avadí, A., Fullana, P., Bala, A., Gazulla, C., Irabien, Á., & Aldaco, R. (2018). Introducing the Green Protein Footprint method as an understandable measure of the environmental cost of anchovy consumption. *Science of the Total Environment*, *621*, 40–53. https://doi.org/10.1016/j.scitotenv.2017.11.148

Lindh, H., Williams, H., Olsson, A., & Wikström, F. (2016). Elucidating the Indirect Contributions of Packaging to Sustainable Development: A Terminology of Packaging Functions and Features. *Packaging Technology and Science*, *29*(4–5), 225–246. https://doi.org/10.1002/pts.2197

Love, D. C., Fry, J. P., Milli, M. C., & Neff, R. A. (2015). Wasted seafood in the United States: Quantifying loss from production to consumption and moving toward solutions. *Global Environmental Change*, *35*, 116–124. https://doi.org/10.1016/j.gloenvcha.2015.08.013

MacLeod, M. J., Hasan, M. R., Robb, D. H. F., & Mamun-Ur-Rashid, M. (2020). Quantifying greenhouse gas emissions from global aquaculture. *Scientific Reports*, *10*(1), 11679.

https://doi.org/10.1038/s41598-020-68231-8

Michaud, J.-C., Farrant, L., Jan, O., Kjær, B., & Bakas, I. (2010). Environmental benefits of recycling - 2010 update. *Waste Resource Action Programme. WRAP*, *March*, 1–252. http://www.wrap.org.uk/sites/files/wrap/Environmental_benefits_of_recycling_2010_update.3b174d59.8816.pdf

Molina-Besch, K. (2016). Prioritization guidelines for green food packaging development. *British Food Journal*, *118*(10), 2512–2533. https://doi.org/10.1108/BFJ-12-2015-0462

Molina-Besch, K., Wikström, F., & Williams, H. (2019). The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture? *International Journal of Life Cycle Assessment*, *24*(1), 37–50. https://doi.org/10.1007/s11367-018-1500-6

Mungkung, R. T., Udo De Haes, H. A., & Clift, R. (2006). Potentials and limitations of life cycle assessment in setting ecolabelling criteria: A case study of Thai shrimp aquaculture product. *International Journal of Life Cycle Assessment*, *11*(1), 55–59. https://doi.org/10.1065/lca2006.01.238

Nhu, T. T., Schaubroeck, T., De Meester, S., Duyvejonck, M., Sorgeloos, P., & Dewulf, J. (2015). Resource consumption assessment of Pangasius fillet products from Vietnamese aquaculture to European retailers. *Journal of Cleaner Production*, *100*, 170–178. https://doi.org/10.1016/j.jclepro.2015.03.030

Pardo, G., & Zufía, J. (2012). Life cycle assessment of food-preservation technologies. *Journal of Cleaner Production*, *28*, 198–207. https://doi.org/10.1016/j.jclepro.2011.10.016

Parker, R. (2018). Implications of high animal by-product feed inputs in life cycle assessments of farmed Atlantic salmon. *International Journal of Life Cycle Assessment*, *23*(5), 982–994. https://doi.org/10.1007/s11367-017-1340-9

Parker, R., Blanchard, J., Gardner, C., Green, B., Hartmann, K., Tyedmers, P., & Watson, R. (2018). Fuel use and greenhouse gas emissions of world fisheries. *Nature Climate Change*, *8*(4), 333–337. https://doi.org/10.1038/s41558-018-0117-x

Parker, R., & Tyedmers, P. (2015). Fuel consumption of global fishing fleets: current understanding and knowledge gaps. *Fish and Fisheries*, *16*(4), 684–696. https://doi.org/10.1111/faf.12087

Pauer, E., Wohner, B., Heinrich, V., & Tacker, M. (2019). Assessing the environmental sustainability of food packaging: An extended life cycle assessment including packaging-related food losses and waste and circularity assessment. *Sustainability (Switzerland)*, *11*(3). https://doi.org/10.3390/su11030925

Pelletier, N., & Tyedmers, P. (2010). Life cycle assessment of frozen tilapia fillets from indonesian lake-based and pond-based intensive aquaculture systems. *Journal of Industrial Ecology*, *14*(3), 467–481. https://doi.org/10.1111/j.1530-9290.2010.00244.x

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science*, *360*(6392), 987–992. https://doi.org/10.1126/science.aaq0216

Poovarodom, N., Ponnak, C., & Manatphrom, N. (2012). Comparative Carbon Footprint of Packaging Systems for Tuna Products. *Packaging Technology and Science*, *25*(5), 249–257. https://doi.org/10.1002/pts.975

Putten, V., Farmery, A. K., Green, B. S., Hobday, A. J., & The, R. W. P. (2015). *environmental impact of two Australian rock lobster fishery supply chains under a changing climate . Journal of Industrial Ecology* . 1–6.

Qiu, X., Chen, S., Liu, G., & Yang, Q. (2014). Quality enhancement in the Japanese sea bass (Lateolabrax japonicas) fillets stored at 4°C by chitosan coating incorporated with citric acid or licorice extract. *Food Chemistry*, *162*, 156–160. https://doi.org/10.1016/j.foodchem.2014.04.037

Rowan, N. J., & Galanakis, C. M. (2020). Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis? *Science of The Total Environment*, *748*, 141362. https://doi.org/10.1016/j.scitotenv.2020.141362

Russell, D. A. M. (2014). Sustainable (food) packaging - an overview. *Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment*, *31*(3), 396–401. https://doi.org/10.1080/19440049.2013.856521

Ryberg, A. M. W., Laurent, A., & Hauschild, M. (2018). Mapping of global plastics value chain and plastics losses to the environment (with a particular focus on marine environment). *United Nations Environment Programme*, 1–99.

Silvenius, F., Grönroos, J., Kankainen, M., Kurppa, S., Mäkinen, T., & Vielma, J. (2017). Impact of feed raw material to climate and eutrophication impacts of Finnish rainbow trout farming and comparisons on climate impact and eutrophication between farmed and wild fish. *Journal of Cleaner Production*, *164*, 1467–1473. https://doi.org/10.1016/j.jclepro.2017.07.069

Spierling, S., Venkatachalam, V., Mudersbach, M., Becker, N., Herrmann, C., & Endres, H.-J. (2020). End-of-Life Options for Bio-Based Plastics in a Circular Economy—Status Quo and Potential from a Life Cycle Assessment Perspective. *Resources*, *9*(7), 90. https://doi.org/10.3390/resources9070090

Svanes, E., Vold, M., & Hanssen, O. J. (2011a). Effect of different allocation methods on LCA results of products from wild-caught fish and on the use of such results. *International Journal of Life Cycle Assessment*, *16*(6), 512–521. https://doi.org/10.1007/s11367-011-0288-4

Svanes, E., Vold, M., & Hanssen, O. J. (2011b). Environmental assessment of cod (Gadus morhua) from autoline fisheries. *International Journal of Life Cycle Assessment*, *16*(7), 611–624. https://doi.org/10.1007/s11367-011-0298-2

Tallentire, C. W., & Steubing, B. (2020). The environmental benefits of improving packaging waste collection in Europe. *Waste Management*, *103*, 426–436. https://doi.org/10.1016/j.wasman.2019.12.045

Tamburini, E., Fano, E. A., Castaldelli, G., & Turolla, E. (2019). Life cycle assessment of oyster farming in the po delta, Northern Italy. *Resources*, *8*(4), 1–17. https://doi.org/10.3390/resources8040170

Tsironi, T. N., & Taoukis, P. S. (2018). Current Practice and Innovations in Fish Packaging. *Journal of Aquatic Food Product Technology*, *27*(10), 1024–1047. https://doi.org/10.1080/10498850.2018.1532479

Turner, D. A., Williams, I. D., & Kemp, S. (2015). Greenhouse gas emission factors for recycling of source-segregated waste materials. *Resources, Conservation and Recycling*, *105*, 186–197. https://doi.org/10.1016/j.resconrec.2015.10.026

van Putten, I. E., Farmery, A. K., Green, B. S., Hobday, A. J., Lim-Camacho, L., Norman-López, A., & Parker, R. W. (2016). The Environmental Impact of Two Australian Rock Lobster Fishery Supply Chains under a Changing Climate. *Journal of Industrial Ecology*, *20*(6), 1384–1398. https://doi.org/10.1111/jiec.12382

Vázquez-Rowe, I., Moreira, M. T., & Feijoo, G. (2011). Life Cycle Assessment of fresh hake fillets captured by the Galician fleet in the Northern Stock. *Fisheries Research*, *110*(1), 128–135. https://doi.org/10.1016/j.fishres.2011.03.022

Vázquez-Rowe, I., Moreira, M. T., & Feijoo, G. (2012). Environmental assessment of frozen common octopus (Octopus vulgaris) captured by Spanish fishing vessels in the Mauritanian EEZ. *Marine Policy*, *36*(1), 180–188. https://doi.org/10.1016/j.marpol.2011.05.002

Vázquez-Rowe, I., Villanueva-Rey, P., Hospido, A., Moreira, M. T., & Feijoo, G. (2014). Life cycle assessment of European pilchard (Sardina pilchardus) consumption. A case study for Galicia (NW Spain). *Science of the Total Environment*, *475*, 48–60. https://doi.org/10.1016/j.scitotenv.2013.12.099

Vázquez-Rowe, I., Villanueva-Rey, P., Iribarren, D., Teresa Moreira, M., & Feijoo, G. (2012). Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixas appellation (NW Spain). *Journal of Cleaner Production*, *27*, 92–102. https://doi.org/10.1016/j.jclepro.2011.12.039

Vázquez-Rowe, I., Villanueva-Rey, P., Mallo, J., De La Cerda, J. J., Moreira, M. T., & Feijoo, G. (2013). Carbon footprint of a multi-ingredient seafood product from a business-to-business perspective. *Journal of Cleaner Production*, *44*, 200–210. https://doi.org/10.1016/j.jclepro.2012.11.049

Vázquez-Rowe, I., Villanueva-Rey, P., Moreira, M. T., & Feijoo, G. (2013). The role of consumer purchase and post-purchase decision-making in sustainable seafood consumption. A Spanish case study using carbon footprinting. *Food Policy*, *41*, 94–102. https://doi.org/10.1016/j.foodpol.2013.04.009

Verghese, K., Crossin, E., Clune, S. J., Lockrey, S., Williams, H., Rio, M., & Wikström, F. (2014). *The greenhouse gas profile of a " Hungry Planet "; quantifying the impacts of the weekly food purchases including associated packaging and food waste of three families*. https://doi.org/10.13140/RG.2.1.3562.6960

Verones, F., Woods, J., Jolliet, O., Boulay, A.-M., & Vazquez-Rowe, I. (2020). Drawing a framework to assess marine plastic litter impacts in life cycle impact assessment: the MarILCA project. *SETAC Europe 30th Annual Meeting*.

Vignali, G. (2016). *Life-Cycle Assessment of Food-Packaging Systems* (pp. 1–22). https://doi.org/10.1007/978-981-287-913-4_1

Wikström, F., Williams, H., & Venkatesh, G. (2016). The influence of packaging attributes on recycling and food waste behaviour – An environmental comparison of two packaging alternatives. *Journal of Cleaner Production*, *137*, 895–902. https://doi.org/10.1016/j.jclepro.2016.07.097

Wikström, F., Williams, H., Verghese, K., & Clune, S. (2014). The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies - A neglected topic. *Journal of Cleaner Production*, *73*, 100–108. https://doi.org/10.1016/j.jclepro.2013.10.042

Williams, H., & Wikström, F. (2011). Environmental impact of packaging and food losses in a life cycle perspective: A comparative analysis of five food items. *Journal of Cleaner Production*, *19*(1), 43–48. https://doi.org/10.1016/j.jclepro.2010.08.008

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., & Gustafsson, A. (2012). Reasons for household food waste with special attention to packaging. *Journal of Cleaner Production*, *24*, 141–148. https://doi.org/10.1016/j.jclepro.2011.11.044

Wojnowska-Baryła, I., Kulikowska, D., & Bernat, K. (2020). Effect of Bio-Based Products on

Waste Management. *Sustainability*, *12*(5), 2088. https://doi.org/10.3390/su12052088

Xanthos, D., & Walker, T. R. (2017). International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. *Marine Pollution Bulletin*, *118*(1–2), 17–26. https://doi.org/10.1016/j.marpolbul.2017.02.048

Ziegler, F., Emanuelsson, A., Eichelsheim, J. L., Flysjö, A., Ndiaye, V., & Thrane, M. (2011). Extended Life Cycle Assessment of Southern Pink Shrimp Products Originating in Senegalese Artisanal and Industrial Fisheries for Export to Europe. *Journal of Industrial Ecology*, *15*(4), 527–538. https://doi.org/10.1111/j.1530-9290.2011.00344.x

Ziegler, F., Nilsson, P., Mattsson, B., & Walther, Y. (2003). Life Cycle Assessment of frozen cod fillets including fishery-specific environmental impacts. *International Journal of Life Cycle Assessment*, *8*(1), 39–47. https://doi.org/10.1007/BF02978747

Ziegler, F., & Valentinsson, D. (2008). Environmental life cycle assessment of Norway lobster (Nephrops norvegicus) caught along the Swedish west coast by creels and conventional trawls - LCA methodology with case study. *International Journal of Life Cycle Assessment*, *13*(6), 487–497. https://doi.org/10.1007/s11367-008-0024-x

Zufia, J., & Arana, L. (2008). Life cycle assessment to eco-design food products: industrial cooked dish case study. *Journal of Cleaner Production*, *16*(17), 1915–1921. https://doi.org/10.1016/j.jclepro.2008.01.010

8. SUPPORTING INFORMATION

Excel file: This supporting information provides the complete data set that was extracted from the scientific literature and used in this article as the basis of the seafood LCA studies review (Table S1) and the data used in Figures 2, 3, 4, and 5 related to the contribution of packaging to the final weight of the seafood products by post-harvest processing (Figure 2) and by main packaging material (Figure 3), and the contribution of packaging to climate change impact in the life cycle of seafood products by type of post-harvesting processing (Figure 4) and packaging main material (Figure 5) (Table S2).

9. FIGURE LEGENDS

Figure 1: Flow diagram of the literature review.

Figure 2: Contribution of packaging to the final weight of the seafood products by post-harvest processing.

Figure 3: Contribution of packaging to the final weight of the seafood products by main packaging material.

Figure 4: Contribution of packaging to climate change impact in the life cycle of seafood products by type of post-harvesting processing.

Figure 5: Contribution of packaging to climate change impact in the life cycle of seafood products by packaging main material.

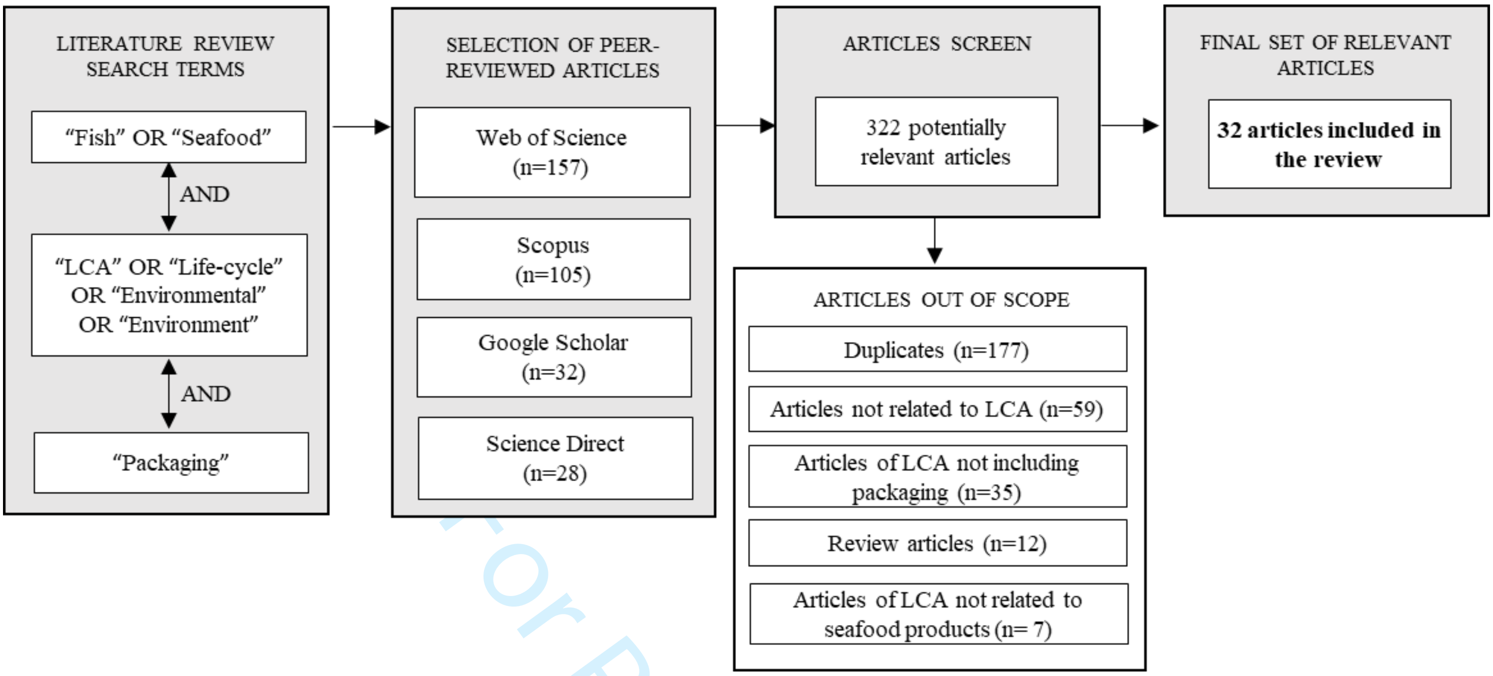

Figure 1. Flow diagram of the literature review.

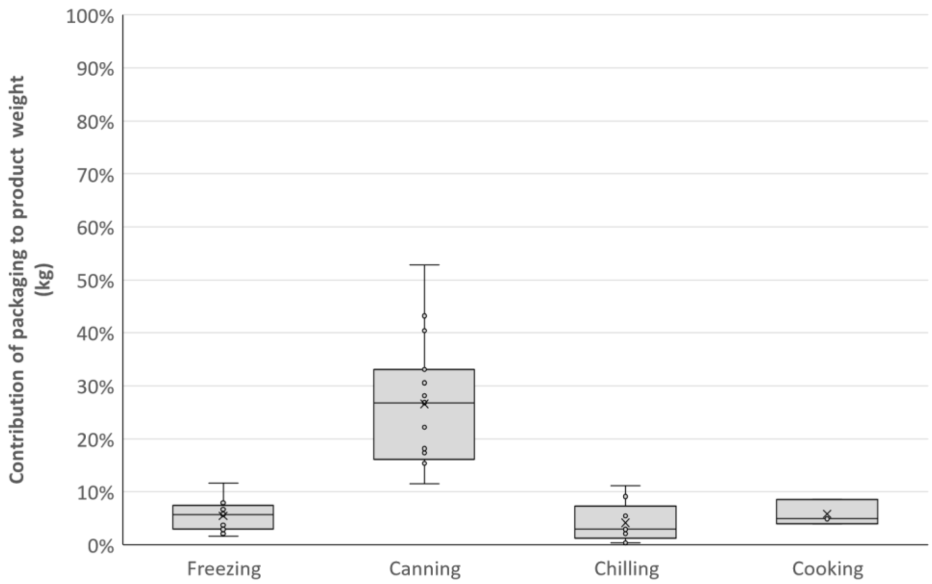

Figure 2. Contribution of packaging to the final weight of the seafood products by post-harvest processing.

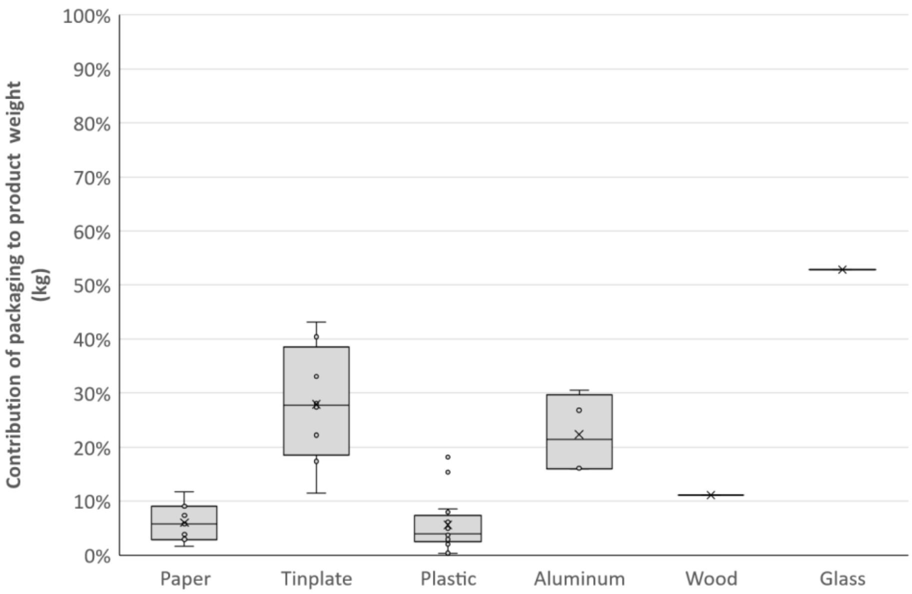

Figure 3. Contribution of packaging to the final weight of the seafood products by main packaging material.

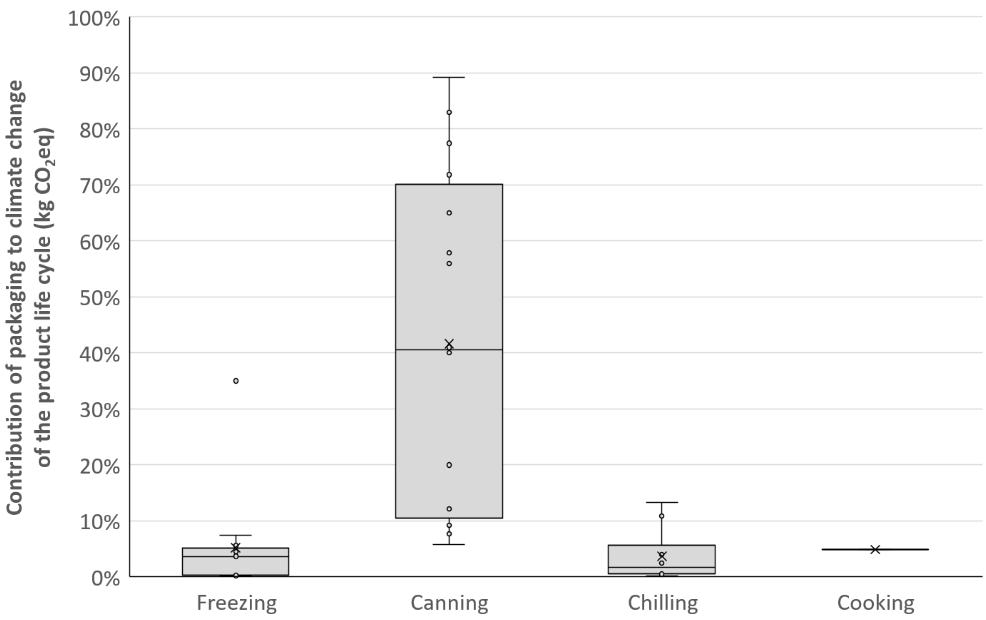

Figure 4. Contribution of packaging to climate change impact in the life cycle of seafood products by type of post-harvesting processing.

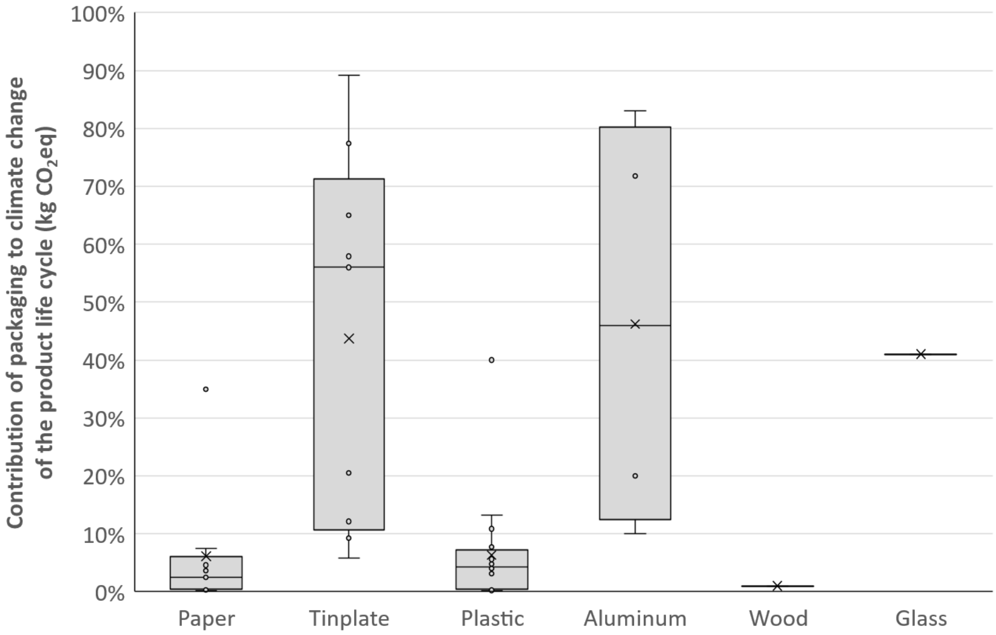

Figure 5. Contribution of packaging to climate change impact in the life cycle of seafood products by packaging main material.

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SUPPORTING INFORMATION FOR:

Lastname, A., Lastname, B. & Lastname, C. (2020). Environmental impact of packaging in the seafood supply chains. *Journal of Industrial Ecology.*

This supporting information provides the complete data set that was extracted from the scientific literature and used in this article as the basis of the seafood LCA studies review (Table S1) and the data used in Figures 2, 3, 4, and 5 related to the contribution of packaging to the final weight of the seafood products by post-harvest processing (Fig. 2) and by main packaging material (Fig. 3), and the contribution of packaging to climate change impact in the life cycle of seafood products by type of post-harvesting processing (Fig. 4) and packaging main material (Fig.5) (Table S2).

If you are providing the data that are used in figures or charts in the main article, please label them as "data_from_figure

_1_in_manuscript", etc.

Table S1: Complete data set extracted from the scientific literature

* LCIA categories legend: GW - Climate change, CED - Cumulative energy demand, AD - Abiotic depletion, A - Acidification, Eut - Eutropl

Num #	Reference	Species groups	Species	Production type
1	Almeida et al., 2015	Sardines	Sardine (Sardina pilchardus)	Fisheries
2.1	Avadí et al., 2014	Anchovy	Peruvian anchoveta (Engraulis ringens)	Fisheries
2.2	Avadí et al., 2014	-	-	-
3.1	Avadí et al., 2015	Tuna	Yellowfin tuna (Thunnus albacares), skipjack tuna (Katsuwonus pelamis), bigeye tuna (Thunnus obesus)	Fisheries
3.2	Avadí et al., 2015	-	-	-
3.3	Avadí et al., 2015	-	-	-
4	Driscoll et al., 2015	Lobster	American lobster (Homarus americanus)	Fisheries
5	Farmery et al., 2014	Lobster	Tasmanian southern rock lobster (Jasus edwardsii)	Fisheries
6	Farmery et al., 2015	Prawn	White banana prawn (Fenneropenaeus merguiensis)	Fisheries
7	Hospido et al., 2006	Tuna	Tuna	Fisheries
8	Iribarren et al., 2010	Mussels	Mussel (Mytilus galloprovincialis)	Aquaculture
9	Iribarren, Moreira, et al., 2010	Mussels	Mussel (Mytilus galloprovincialis)	Aquaculture
10.1	Iribarren, Moreira, et al., 2010b	Mussels	Mussel (Mytilus galloprovincialis)	Aquaculture
10.2	Iribarren, Moreira, et al., 2010b	-	-	-
11.1	Iribarren, Moreira, et al., 2010c	Mussels	Mussel (Mytilus galloprovincialis)	Aquaculture
11.2	Iribarren, Moreira, et al., 2010c	-	-	-
11.3	Iribarren, Moreira, et al., 2010c	-	-	-
12.1	Laso et al., 2017	Anchovy	European anchovy (Engraulis encrasicolus)	Fisheries
12.2	Laso et al., 2017	-	-	-
12.3	Laso et al., 2017	-	-	-
12.4	Laso et al., 2017	-	-	-
13.1	Laso et al., 2018	Anchovy	European anchovy (Engraulis encrasicolus)	Fisheries
13.2	Laso et al., 2018	-	-	-
14	Mungkung et al., 2006	Shrimp	Shrimp	Aquaculture
15	Nhu et al., 2015	Catfish	Striped catfish (Pangasius hypophthalmus)	Aquaculture
16	Pardo & Zufía, 2012	Fish (sp non ident	Pre-cooked dish of fish and vegetables	-
17	Parker, 2018	Salmon	Atlantic salmon (Salmo salar)	Aquaculture
18	Pelletier & Tyedmers, 2010	Tilapia	Indonesian tilapia (Oreochromis niloticus)	Aquaculture
19	Silvenius et al., 2017	Trout	Rainbow trout	Aquaculture
20.1	Svanes et al., 2011	Cod	Cod (Gadus morhua)	Fisheries
20.2	Svanes et al., 2011	-	-	-
20.3	Svanes et al., 2011	-	-	-
20.4	Svanes et al., 2011	-	-	-

21.1	Svanes et al., 2011b	-	-	-
21.2	Svanes et al., 2011b	-	-	-
21.3	Svanes et al., 2011b	Cod	Cod (Gadus morhua)	Fisheries
22	Tamburini et al., 2019	Oysters	Oyster (Crassostrea gigas)	Aquaculture
23.1	van Putten et al., 2016	Lobster	Southern rock lobster (Jasus edwardsii)	Fisheries
23.2	van Putten et al., 2016	-	Tropical rock lobster (Panulirus ornatus)	-
23.3	van Putten et al., 2016	-	Tropical rock lobster (Panulirus ornatus)	-
24	Vázquez-Rowe et al., 2011	Hake	European hake (Merluccius merluccius)	Fisheries
25	Vázquez-Rowe, Moreira, et al., 2(	Octopus	Octopus (Octopus vulgaris)	Fisheries
26	Vázquez-Rowe et al., 2013	Hake	Patagonian grenadier hake (Macruronus magellanicus)	Fisheries
27	Vázquez-Rowe, Villanueva-Rey, M	Hake	Patagonian grenadier hake (Macruronus magellanicus)	Fisheries
28	Vázquez-Rowe et al., 2014	Sardines	Sardine (Sardina pilchardus)	Fisheries
29	Ziegler & Valentinsson, 2008	Lobster	Norway lobster (Nephrops norvegicus)	Fisheries
30	Ziegler et al., 2003	Cod	Cod (Gadus morhua)	Fisheries
31.1	Ziegler et al., 2011	Shrimp	Southern pink shrimp (Penaeus notialis)	Fisheries
31.2	Ziegler et al., 2011	-	-	-
32	Zufia & Arana, 2008	Tuna	Tuna	Fisheries

hication, HT - Human toxicity, ET - Ecotoxicity, OD - Ozone layer depletion, PO - Photochemical oxidation,

Functional unit	Post-harvest processing
1 kg of edible canned sardines in olive oil	Canning
1 kg of fish product	Canning
-	Canning (curing)
1 tonne of tuna product	Canning
-	Canning (pouch)
-	Freezing (vacuum bagged)
1 tonne live lobster	Chilling
1 kg of live lobster	Chilling
1 kg of frozen banana prawn	Freezing
1 tonne of raw tuna entering the factory	Canning
Triple pack of round can of canned mussels	Canning
65 tonnes of $CaCO_3$ products and 278 tonnes of mussel pâté	Canning
1 kg of mussels product	Canning
-	Chilling
35 kg of canned mussels	Canning
40 kg of fresh mussels	Chilling
20 kg of frozen mussels	Freezing
1 kg of raw anchovy entering the factory	Canning
-	-
-	-
-	-
1 kg of fresh European anchovy entering the factory	Canning
-	Canning (curing)
1.8 kg of frozen shrimp	Freezing
1 tonne of Pangasius fillets leaving the factory	Other (freezing and MAP)
1 kg of the pre-cooked dish of fish and vegetables	Other (cooking)
1 kg of head-on gutted salmon	Chilling
1 tonne of tilapia	Freezing
1 tonne of skinless fillet of fish	Chilling
1 kg of cod wetpack	Freezing
1 kg of individually quick frozen cod product	Freezing
1 kg of fish burger	Freezing
1 kg of loins product	Chilling

1 kg fish-burger	Freezing
1 kg cod loins	Chilling
1 kg wetpack frozen	Freezing
1 kg of commercial fresh oysters at farm gate	Chilling
1 kg live Southern rock lobster	Chilling
1 kg live Tropical rock lobsters	Chilling
1 tail – 350g Tropical rock lobster	Freezing
500 g of raw gutted fresh hake fillet reaching the household of na average consumer	Chilling
24 kg carton of frozen octopus up to the import	Freezing
1 package (324 g of sticks)	Freezing
1 package of frozen fish sticks of Patagonian grenadier	Freezing
17.26 g of protein supplied by one can of sardines (85.0 g) in olive oil	Canning
300 g of Norway lobster tails	Other (cooking)
400 g frozen cod fillets	Freezing
1 kg of shrimp and packaging material at the point of import to Europe	Freezing, industrial
-	Freezing, artisanal
2 kg tray of pasteurized tuna with tomato	Other (cooking, pasteurizing)

, ALO - Agircultural land occupation, ULO - Urban land occupation, NLT - Natural land transform

Primary packaging	Primary packaging main material
Aluminum can	Aluminum
Tinplate can	Tinplate
Tinplate and aluminium can	Tinplate
Tinplate can	Tinplate
Retort pouch (plastic)	Plastic
Thermo-shrinkable bag (plastic)	Plastic
Package made by corrugated cardboard, polystyrene, cotton fiber	Paper
Polystyrene boxes with wood wool and ice packs	Plastic
Cardboard	Paper
Tinplate can	Tinplate
Tinplate can	Tinplate
Tinplate can	Tinplate
Tinplate can	Tinplate
Mesh and label of high density polyethylene (HDPE)	Plastic
Tinplate can	Tinplate
Mesh and label of high density polyethylene (HDPE)	Plastic
Paperboard and plastic	Paper
Aluminum can	Aluminum
Tinplate can	Tinplate
Glass jar	Glass
Plastic packaging	Plastic
Aluminum can and cardboard box	Aluminum
Aluminum can and cardboard box	Aluminum
-	
Modified atmosphere packaging (MAT) made of polyethylene, cardboard	
Polypropylene	Plastic
Polyethylenelined polystyrene boxes	Plastic
Cardboard and plastic	Paper
Plastic	Plastic
Polyamide and polyethylene	Plastic
Polyamide and polyethylene	Plastic
Low density polyethylene (LDPE) and corrugated board	Plastic
High density polyethylene (HDPE) tray and plastic film	Plastic

Low density polyethylene (LDPE) and corrugated board	Plastic
High density polyethylene (HDPE) tray and plastic film	Plastic
Polyamide and polyethylene	Plastic
Wooden baskets	Wood
Styrofoam boxes (polystyrene)	Plastic
Styrofoam boxes (polystyrene)	Plastic
Waxed cardboard box	Paper
High density polyethylene (HDPE)	Plastic
Corrugated board and polyethylene	Paper
Cardboard box with polyethylene and retractable polyolefin	Paper
Cardboard and polyethylene boxes	Paper
Tinplate can	Tinplate
Disposable bucket of polypropylene	Plastic
Low density polyethylene (LDPE) and laminated cardboard	Plastic
Cardboard package	Paper
Cardboard package	Paper
Vacuum-packaged made of high density polyethylene (HDPE) with a polyethylene film and na polyamide nylon (OPA) barrier layer	Plastic

ıation, SS - Single score, SIP - Seafloor impact potential, D - Discard reporting, BRU - Biotic resource use.

Other packaging	Geographic scope	System boundaries	Allocation
Corrugated board	Portugal	Cradle to gate	Mass
-	Peru	Cradle to market	Mass
-	-	-	-
-	Ecuador	Cradle to gate	Mass
-	-	-	-
-	-	-	-
-	Canada	Cradle to market	Mass
-	Produced in Australia, marketed in China	Cradle to market	N/A
-	Australia	Cradle to market	N/A
Cardboard box and plastic film	Spain	Cradle to grave	N/A
Cardboard	Spain	Cradle to grave	Mass
Cardboard and packaging film	Spain	Cradle to gate	N/A
Cardboard for transport and low density polyethylene (LDPE) bag for consumption phase	Spain	Cradle to grave	N/A
Shopping bag of low density polyethylene (LDPE) for consumption phase	-	-	-
Cardboard (can) and plastic bag low density polyethylene (LDPE) for consumption phase	Spain	Cradle to gate	N/A
Shopping bag of low density polyethylene (LDPE) for consumption phase	-	-	-
Shopping bag of low density polyethylene (LDPE) for consumption phase	-	-	-
Cardboard boxes and and low density polyethylene (LDPE) film	Spain	Cradle to grave	N/A
Cardboard boxes and and low density polyethylene (LDPE) film	-	-	-
Cardboard boxes and and low density polyethylene (LDPE) film	-	-	-
Cardboard boxes and and low density polyethylene (LDPE) film	-	-	-
Corrugated cardboard boxes and low density polyethylene (LDPE) film	Spain	Cradle to grave	Mass
Corrugated cardboard boxes and lowdensity polyethylene (LDPE) film	-	-	-
-	Thailand	Cradle to grave	N/A
-	Produced in Vietnam, processed in Belgium	Cradle to market	Exergy
-	-	Cradle to gate	Mass
-	Australia	Cradle to market	Mass
-	Indonesia	Cradle to market	Energy
-	Finland	Cradle to gate	Economic
Polyethylene film, wood pallet and carton	Norway	Cradle to market	Mass, economic,
Corrugated board and wood pallet	-	-	-
Low density polyethylene (LDPE) and wood pallet	-	-	-
Expanded polystyrene (EPS) and low density polyethylene (LDPE) film	-	-	-

Low density polyethylene (LDPE) and wood pallet	Norway	-	-
Expanded polystyrene (EPS) and low density polyethylene (LDPE) film	-	-	-
Polyethylene film, wood pallet and carton	-	Cradle to market	Mass and econo
-	Italy	Cradle to gate	N/A
-	Australia	Cradle to market	Mass
-	-	-	-
-	-	-	-
Polystyrene and fish boxes for processing stage	Spain	Cradle to grave	Mass
Pallets	Mauritania	Cradle to gate	Mass
-	Produced in Chile, processed in Spain	Cradle to gate	Mass
-	Spain	Retail store up to the h	Mass
Cardboard boxes, larger boxes of corrugated board with plastic film	Spain	Cradle to grave	N/A
-	Sweden	Cradle to grave	Economic
Low density polyethylene (LDPE)	Sweden	Cradle to grave	Economic
-	Senegal	Cradle to gate	Economic
-	-	-	-
-	Spain	Cradle to grave	N/A

LCI data source (background)	LCIA Method
ecoinvent 2.0	CML-IA
ecoinvent 2.3	ReCiPe
-	-
ecoinvent 2.2	ReCiPe
-	-
-	-
several DB (ecoinvent 1, LCAFood DK, IDEMAT, BUWAL, Franklin)	CML + CED
Australian dataset + ecoinvent	CML 2 Baseline
Australian dataset + ecoinvent	CML 2 Baseline
ecoinvent, BUWAL, IVAM LCA, Papers	CML
ecoinvent, BUWAL 50	Monocriteria (PAS 2050)
ecoinvent	CML 2001
ecoinvent	CML 2000
-	-
ecoinvent	CML 2001
-	-
-	-
PE + ecoinvent 3.1	IChemE (sustainable metrics)
-	-
-	-
-	-
ecoinvent + PE International (GaBi)	CML-IA (midpoint) & ReCiPe (e
-	-
DB included in SimaPro	CML 2
ecoinvent 2.2	Energetic & Exergetic metrics
ecoinvent 2.0	ReCiPe (midpoint)
ecoinvent 3.0 & Agri-footprint 2.0	CML-IA
-	CML 2000 + CED
ecoinvent	2 criterion (IPCC for GW, Seppa
ecoinvent 1.3/2.0	CML 1992 + CED
-	-
-	-
-	-

-	-
-	-
ecoinvent 1.3/2.0	CML 2 + CED
ecoinvent 3.6	Eco-indicator 99 (endpoint) + F
ecoinvent 3.0	CML
-	-
-	-
ecoinvent	CML 2000
ecoinvent 2 (2007)	CML 2000
ecoinvent	Monocriteria (IPCC 2001)
ecoinvent	Monocriteria (IPCC 2007)
ecoinvent 2.2	ReCiPe
ecoinvent 1.2	CML-IA
CIT-Ekologik	CIT-Ekologik
ecoinvent 2.0	CML 2
-	-
APME, ETH, BUWAL	CML

LCIA categories *
GW, AD, A, Eut, OD, ET, PO, CED
GW, A, Eut, ALO, WD, AD, HT, ET, CED, BRU, SS
-
GW, HT, ME, Eut, AD, PMF, POF, SS
-
-
GW, A, OD, AD, CED
GWP, Eut, CED, WU, ET
GWP, Eut, CED, WU, ET
GW, OD, E, A, POF, AD
GW
GW, A, OD, AD, Eut, ET, HT
GW, AD, A, OD, Eut, POF, ET, HT
-
GW, A, OD, AD, Eut, POF, ET, HT
-
-
GW, A, PO, OD, ET, Eut, Aquatic oxygen deman, HT
-
-
-
GW, A, Eut, SS
-
GW, AD, OD, HT, ET, POF, A, Eut
CEENE, CED, CExD
GW, A, Eut, PO, WD, CED
GW, A, Eut, PO, OD, CED
GW, A, Eut, CED, BRU
GW, Eut
GW, OD, PO, A, Eut, CED
-
-
-

-

-

GW, OD, PO, A, Eut, CED
GW, HT, OD, A, Eut, ET, AD, Sea conversion & occupation
GW, A, Eut, OD, CED
-
-
GW, AD, A, Eut, OD, ET

GW, AD, A, Eut, PO, ODP, METP, SIP, D
GW

GW

GW, OD, HT, POF, PMF, IR, A, Eut, ET, ALO, ULO, NLT, WD, AD

GW, AD, A, ET, PO, Eut
GW, A, Eut, ET, PO
GW, A, Eut, POC, OD, HT, ET, CED

-
GW, A, ET, OD, Eut, HT, AD

Table S2: Data sets from figures 2, 3, 4 and 5 data in the manuscript

Num #	Reference	Type	Main packaging material	Packaging weight (kg)
1	Almeida et al., 2015	Canning	Aluminum	0.4
2.1	Avadí et al., 2014	Canning	Tinplate	0.1
2.2	Avadí et al., 2014	Canning	Tinplate	0.2
3.1	Avadí et al., 2015	Canning	Tinplate	10590814.0
3.2	Avadí et al., 2015	Canning	Plastic	561667.6
3.3	Avadí et al., 2015	Freezing	Plastic	206552.0
4	Driscoll et al., 2015	Chilling	Paper	100.0
5	Farmery et al., 2014	Chilling	Plastic	0.0
6	Farmery et al., 2015	Freezing	Paper	0.0
7	Hospido et al., 2006	Canning	Tinplate	447.4
8	Iribarren et al., 2010	Canning	Tinplate	93.7
9	Iribarren, Moreira, et al., 2010	Canning	Tinplate	108.7
11.1	Iribarren, Moreira, et al., 2010c	Canning	Tinplate	0.8
11.2	Iribarren, Moreira, et al., 2010c	Chilling	Plastic	3.8
11.3	Iribarren, Moreira, et al., 2010c	Freezing	Paper	0.1
12.1	Laso et al., 2017	Canning	Aluminum	0.1
12.2	Laso et al., 2017	Canning	Tinplate	0.2
12.3	Laso et al., 2017	Canning	Glass	0.7
12.4	Laso et al., 2017	Canning	Plastic	0.1
13.1	Laso et al., 2018	Canning	Aluminum	118.3
13.2	Laso et al., 2018	Canning	Aluminum	299.5
16	Pardo & Zufía, 2012	Cooking	Plastic	51.5
17	Parker, 2018	Chilling	Plastic	0.0
18	Pelletier & Tyedmers, 2010	Freezing	Paper	132.5
19	Silvenius et al., 2017	Chilling	Plastic	-
20.1	Svanes et al., 2011	Freezing	Plastic	0.0
20.2	Svanes et al., 2011	Freezing	Plastic	0.0
20.3	Svanes et al., 2011	Freezing	Plastic	0.3
20.4	Svanes et al., 2011	Chilling	Plastic	0.1
22	Tamburini et al., 2019	Chilling	Wood	0.1
23.1	van Putten et al., 2016	Chilling	Plastic	0.0
23.2	van Putten et al., 2016	Chilling	Plastic	0.0
23.3	van Putten et al., 2016	Freezing	Paper	0.0
24	Vázquez-Rowe et al., 2011	Chilling	Plastic	1.5
25	Vázquez-Rowe, Moreira, et al., 20	Freezing	Paper	393.8
26	Vázquez-Rowe et al., 2013	Freezing	Paper	25.8
28	Vázquez-Rowe et al., 2014	Canning	Tinplate	-
29	Ziegler & Valentinsson, 2008	Cooking	Plastic	0.8
30	Ziegler et al., 2003	Freezing	Plastic	81400.0
31.1	Ziegler et al., 2011	Freezing	Paper	-
31.2	Ziegler et al., 2011	Freezing	Paper	-
32	Zufia & Arana, 2008	Cooking	Plastic	80.2

Final product weight including packaging (kg)	Contribution of packaging to the product weight (%)	Climate change for FU (kgCO2eq/kg of food)	Climate change of packaging (kgCO2eq/kg of food)
1.4	30.6%	7.7	5.5
1.1	11.5%	1.9	1.2
1.2	17.4%	3.7	2.1
31982814.0	33.1%	8.0	1.6
3091667.6	18.2%	4.1	0.3
3074552.0	6.7%	3.8	0.0
1100.0	9.1%	-	0.2
1.0	2.9%	31.0	1.0
1.0	2.9%	7.2	0.1
1107.4	40.4%	8.3	1.0
342.7	27.3%	17.8	15.9
386.5	28.1%	1.8	0.2
1.8	43.2%	9.8	0.6
1003.8	0.4%	13.9	-
1.1	5.7%	9.5	-
0.7	16.1%	-	-
0.8	22.2%	-	-
1.3	52.8%	-	-
0.7	15.4%	-	-
743.3	15.9%	-	-
1116.5	26.8%	-	-
1051.5	4.9%	-	0.1
1.0	2.1%	13.2	-
1132.5	11.7%	2.0	0.1
-	-	5.4	0.0
0.4	3.7%	3.6	0.2
0.4	7.9%	3.7	0.2
5.3	6.1%	1.8	0.1
2.1	5.4%	7.6	0.3
1.1	11.1%	1.9	0.0
1.0	2.9%	15.8	0.2
1.0	2.9%	9.3	0.0
0.4	3.8%	3.2	0.0
501.5	0.3%	3.8	0.8
24393.8	1.6%	7.8	0.0
349.3	7.4%	2.2	0.1
-	-	3.4	2.6
8.8	8.6%	11.1	0.5
3959400.0	2.1%	7275.0	19.5
-	-	37.0	2.8
-	-	8.0	2.8
2000.0	4.0%	-	-

Contribution of packaging to climate change of the product life cycle (%)
71.8%
65.0%
57.9%
20.5%
7.7%
0.2%
2.5%
3.1%
0.7%
12.1%
89.2%
9.2%
5.8%
0.5%
0.5%
83.0%
56.0%
41.0%
40.0%
10.0%
20.0%
-
0.5%
3.7%
13.2%
4.5%
4.8%
5.6%
4.0%
1.0%
1.0%
0.2%
0.2%
10.9%
0.3%
4.6%
77.4%
4.9%
0.3%
7.5%
35.0%
-