Waste management under a life cycle approach as a tool for a circular economy in the canned anchovy industry

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ABSTRACT

The anchovy canning industry has high importance in the Cantabria Region (North Spain) from economic, social and touristic points of view. The Cantabrian canned anchovy is world-renowned owing to its handmade and traditional manufacture. The canning process generates huge amounts of several food wastes, whose suitable management can contribute to benefits for both the environment and the economy, closing the loop of product life cycle. Life cycle assessment methodology was used in this work to assess the environmental performance of two waste management alternatives: head and spine valorisation to produce fishmeal and fish oil and anchovy meat valorisation to produce anchovy paste.

Fuel oil production has been a hotspot of the valorisation of heads and spines, so several improvements should be applied. With respect to anchovy meat valorisation, the production of polypropylene and glass for packaging was the least environmentally friendly aspect of the process.

Furthermore, the environmental characterisation of anchovy waste valorisation was compared with incineration and landfilling alternatives. In both cases, the valorisation management options were the best owing to the avoided burdens associated with the processes. Therefore, it is possible to contribute to the circular economy in the Cantabrian canned anchovy industry.

KEYWORDS: canning industry, anchovies, circular economy, food waste, valorisation, life cycle assessment

INTRODUCTION

The rapid growth in world population over the last 50 years has caused an immense increase in the demand for food. It has been estimated that the world population will reach 9 billion by 2050, requiring a 60–70 % increase in food production (Moraes et al. 2014). However, the FAO estimates that more than 1.3 billion t of food are wasted every year (Bräutigam et al. 2014). This means that significant quantities of resources employed for food production are used in vain and generate a significant environmental impact, such as an increase in the quantity of greenhouse gases generated (FAO 2011). Food is lost or wasted along the whole food supply chain: on the farm and on the harvest, in manufacture, in markets and restaurants and at home. Food loss and waste in industrialised countries are as high (over 40 % occurs at retail and consumer level) as in developing countries (over 40 % of food losses happen after harvesting or cultivation and during processing). Food waste depends on the food sector and the world region. Moreover, some other factors affecting waste losses include inadequate storage and/or transport at the food supply chain, overproduction, lack of demand for some products at certain times of the year, product and packaging damage or insufficient meal planning leading to too much food being purchased or prepared (FAO 2011).

In Europe, approximately 30 % of food losses are related to fishing, post-catch, and to the processing, distribution and consumption of fish and seafood. In particular, the processing stage represents 5 % of fish losses due to the generation of by-products that are edible for human consumption (FAO 2011). Heads and spines compose the unavoidable fish losses, whereas fish remains form the avoidable fish losses. In this context, the fish canning industry is an important activity that generates large amounts of wastes. Spain is the top European producer of canned food with more than 343,000 t of product weight produced, valued at 1,500 million euro (FAO 2015). As one of the largest fishing nations in Europe, Spain has historically abundant consumption and production of fish. Among the different types of fishes, anchovy is the 5th most popular. However, consumer preferences show a considerable discrepancy depending on region. For example, in Cantabria Region (North Spain), the anchovy is the 2nd most preferred fish (Eurofish 2012). In particular, the quality of the Cantabrian canned anchovy is world-renowned; owing to its handmade and traditional manufacture, consumers consider the product to be gourmet canned food. However, its production generates a huge amount of solid and liquid wastes (approximately 9,000 t year^{-1}) (IHOBE 1999).

Therefore, the European Commission has promoted the reutilization of waste by means of the circular economy. This concept, introduced in several environmental policy initiatives (European Commission 2015a, 2015b, 2015c and 2015d), aims to keep the added value in products for as long as possible and eliminate waste. Circular economy in the food sector has always been oriented towards the packaging (European Commission 2015e) improving the design to make it more eco-efficient and recycling the packaging by means of valorisation. This paper presents a circular economy approach based on the study of several management options of wastes generated in the canned anchovy manufacturing (Figure 1).

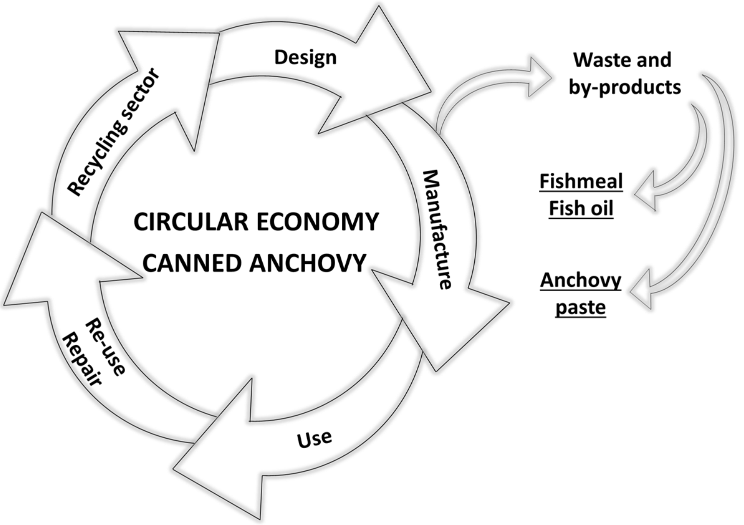

Figure 1. Circular economy approach in the canned anchovy sector.

In the canned anchovy sector, the management of two specific types of wastes must be highlighted: heads and spines, and anchovy meat. These food losses can be treated or valorised. On the one hand, heads and spines removed at the beginning of the canning process and in the filleting step, respectively, can be used to produce fishmeal and fish oil. In 2012, the global fish production intended to direct human consumption, including fisheries and aquaculture, was 158 million tonnes whereas the production of fishmeal and fish oil reached 16.3 million tonnes. Owing to the growing demand for these manufacturing products and its rising prices, the production of fishmeal from fish by-products has increased. According to recent estimates, in 2012 about 35 % of the world fishmeal production (5.7 million tonnes) was obtained from fish residues (FAO 2014). If the percentage of use of fish residues increases to 100 %, approximately 33 million tonnes of fresh fish would be used for direct human consumption. Moreover, an ethical discussion regarding whether the fish should be used for direct human consumption or fishmeal production is present in society (Wijkström 2009). When fish is converted into fishmeal, less fish is provided as human food, and an unsustainable increase in fishing pressure extinguishes some wild fish resources. Therefore, the valorisation of heads and spines into fishmeal could reduce the use of fresh fish for indirect human consumption by potentially 21 %.

On the other hand, anchovy meat composed of remaining anchovies and broken anchovies from the filleting step can be used to produce anchovy paste. This product could replace tuna or mussel pâté because of its similar protein content.

The valorisation rather than disposal of anchovy waste could reduce the environmental impacts of the canning process. In this sense, the use of the life cycle assessment (LCA) methodology will help determine the best waste management alternative. LCA is a powerful tool for addressing the environmental aspects and potential environmental impacts throughout a product´s life cycle, from raw material acquisition to final disposal (Allesch and Brunner 2014). LCA has already been used in assessing the management of wastes from the mussel sector (Iribarren et al. 2010a) and anchovy fishing (Freón et al. 2014) and to analyse several Peruvian anchovy products, such as canned, fresh, frozen, salted and cured (Avadí et al. 2014). However, the management of anchovy wastes has not yet been assessed from an LCA approach. Therefore, the aim of this work is to analyse the treatment and valorisation of anchovy wastes, specifically head and spines and anchovy meat. In particular, the main objectives of this research include the following:

- Identification, using an attributional LCA methodology, of the hotspots in the production of fishmeal and fish oil from heads and spines.

- Identification of the environmental hotspots in the production of anchovy paste from the rest of anchovies.
- Comparison of the environmental impacts of anchovy wastes valorisation versus end-of-life by landfilling and incineration.

LCA FRAMEWORK

Case study

The canning factory receives the fresh anchovies from the harbour. The fish is beheaded and placed in layers with a bed of salt between each layer of fish for 6 months. After curing, the skin is removed by means of cold and hot water (scalding), and each anchovy is cut and filleted by hand. The anchovy fillets are packed in cans filled with olive oil. Finally, the cans are sealed, washed, codified and packed.

Throughout the anchovy processing, approximately 60 % of the anchovy weight is lost. These losses include the heads, entrails, spines and remaining and broken anchovies. Remaining and broken anchovies (40-42 %) could be used for human consumption and, according to the nutritional value of anchovy fish (FAO 1989), these losses are about 50 kcal 100 g^{-1} of anchovy fish.

Figure 2 displays the systems comprising the management of anchovy wastes. Fish solid residues composed of heads and spines are sent to a fishmeal plant to produce fishmeal and fish oil. Remaining anchovy meat and broken anchovies can be used to make anchovy paste.

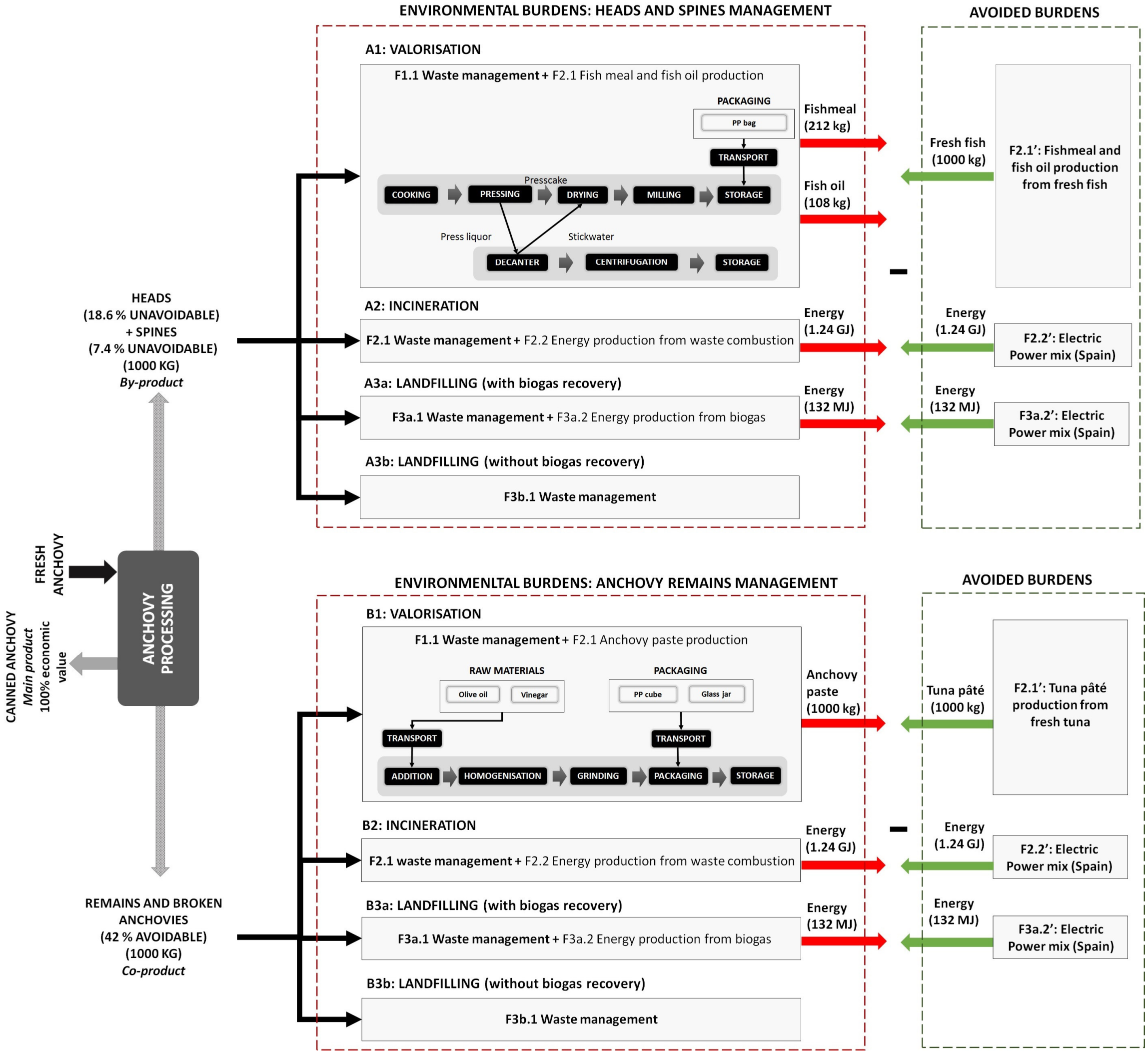

Figure 2. Flow diagram of the management of fish products in the canned anchovy industry. Comparison between the different alternatives: valorisation, incineration and landfilling. System expansion and avoided burdens.

System boundaries

Valorisation of heads and spines

Figure 2 shows the steps of the valorisation of heads and spines: (i) heating, (ii) pressing, (iii) separation of the liquid phase into oil and water (stickwater), (iv) evaporation of the stickwater into a concentrate, (v) drying of the solid material (presscake), (vi) grinding of the dried material and (vii) storage.

Heads and spines are transported to the fishmeal plant. However, the transport was not considered because the distance between the canning plant and the fishmeal plant is less than 1 km. First, the heads and spines are cooked to coagulate the protein and liberate the water and oil content. The pressing produces two streams: a solid phase (presscake) containing 60–80 % of the oil-free dry matter (protein, bones) and the oil, and a liquid phase (press liquor), which is a mixture of fish oil, water and soluble protein. The main part of the sludge from the press liquor is removed in a decanter, and the fish oil is subsequently removed by a centrifuge. The stickwater from the separation stage is concentrated and mixed with the presscake. Finally, the presscake is dehydrated, milled and mixed with an antioxidant. The final product, fishmeal, is stored in bags of polypropylene with a capacity of 50 kg, whereas the fish oil is stored in tanks (FAO 1986).

Anchovy meat valorisation

Figure 2 shows the steps of the manufacture of anchovy paste conducted in the canning factory: (i) addition, (ii) homogenisation, (iii) grinding, (iv) packaging and (v) storage.

Two types of anchovy pastes can be produced: on the one hand, pure anchovy paste, in which the anchovy meat is grinded directly to obtain the paste. The resulting paste is transferred to a filling machine and packaged. The packaging, composed of a cube of propylene, is transported to the canning factory. The final product is weighed and stored in the canning plant.

On the other hand, anchovy paste with olive oil is composed of anchovy meat, olive oil and vinegar. The mixture comprises 97 % anchovy, 2 % olive oil and 1 % vinegar. The ingredients are mixed, grinded and transferred to a filling machine. The package is formed by a glass jar with a 453 g capacity and transported to the canning factory. The efficiency of both processes is 100 %, so wastes are not generated. Data on anchovy paste were collected from a Cantabrian canning industry that produced approximately 19,000 kg in 2014. From this amount, 11,300 kg were pure paste (59 %) and 7,700 kg were anchovy paste with oil (41 %).

Functional unit

The functional unit (FU) chosen for the valorisation of anchovy heads and spines was 1 t of anchovy wastes entering the flour plant. Similarly, the FU for the valorisation of the remaining and broken anchovies was 1 t of anchovy meat entering the paste processing. It was considered that from 1 t of anchovy meat (input of the process), 60 % is used to manufacture pure anchovy paste (595 kg) and the remaining 41 % is converted to anchovy paste with olive oil (405 kg). The comparison between valorisation and other management options was made based on 1 t of wastes for management.

Allocations

Multifunctional processes require the use of allocations to determine the environmental impacts of each product. This occurs when a process is shared between several product systems and it is unclear to which product the environmental impacts may be allocated. In this case, the allocation problem is a multi-output process (in which a process generates several products), and the environmental burdens must be distributed among the different products or processes (Finnveden et al. 2009). In particular, the production of canned anchovies generates two products: canned anchovies and anchovy remains. According to Ayer et al. (2007), an economic allocation was used to distribute the environmental impacts between the main product (canned anchovy) and the co-product (anchovy remains). In this case, 100 % of the environmental burden was allocated to the canned anchovy because the co-product accounted for only 7 % of the total economic value. Therefore, the environmental impact of the input anchovy remains to the valorisation system was zero. However, when the management alternatives were compared, it was possible to adopt an avoided burden approach since valorisation provides commercial products. The latter approach is discussed in the section “Comparison of management alternatives”.

Data acquisition

Data on the production of fishmeal and fish oil were taken from the literature. The consumption of energy, water and fuel oil were obtained from FAO (1986) and belong to a fishmeal plant with a production of more than 500 t day^{-1}. The yield of the process and the consumption of antioxidants were acquired from Shepherd and Jackson (2013). Primary data on anchovy paste were collected from a Cantabrian canning factory that produced approximately 19,000 kg in 2014: 11,300 kg of pure paste and 7700 kg of paste with olive oil. Regarding the management alternatives, the model of organic matter incineration developed by Margallo et al. (2014a) was considered for the incineration of anchovy wastes, whereas data on landfilling were taken from the PE database (PE International 2014). With respect to the processes used in the system expansion, data on anchovy fishing were collected from Freón et al. (2014), whereas tuna fishing and pâté processing came from Hospido et al. (2005) and Iribarren et al. (2010a), respectively. Moreover, the PE (PE International 2014) and BUWAL (BUWAL 250 1996) databases were chosen for background processes.

Assumptions

With regard to the cut-offs, all material and energy inputs with a cumulative total of at least 98 % of the total mass and energy inputs were included. However, flows that do not meet this criterion but are thought to potentially have a significant environmental impact have also been included. Therefore, the production of olive oil and polypropylene were considered, but the manufacture of vinegar and the antioxidant were not.

The transportation of raw materials such as olive oil and the packaging was carried out by truck. The capacity of the trucks was chosen considering the most similar options among those available from the database, and the transportation distances were estimated by means of road guides: olive oil (850 km), cube of polypropylene (60 km), glass jar (730 km) and bags of polypropylene (60 km).

Life Cycle Inventory (LCI)

For both valorisation systems, the quantification of capital goods was avoided on the basis of the long lifespan estimated for the installations (more than 20 years in both cases) (Renou et al. 2008). Table 1 shows the inputs and outputs for the valorisation of 1 t of heads and spines to produce fishmeal and fish oil and for the valorisation of 1 t of anchovy meat to produce anchovy paste, as “pure” anchovy paste and anchovy paste with olive oil.

Table 1. Inventory for anchovy wastes valorisation (F.U.: 1 t of anchovy wastes).

		Heads and spines valorisation	**Anchovy meat valorisation**	
	Units	**Fishmeal and fish oil**	**“Pure” anchovy paste**	**Anchovy paste with olive oil**
Inputs				
Heads and spines	kg	1000	-	-
Anchovy meat	kg	-	595	405
Olive oil	kg	-	-	8.1
Vinegar	kg	-	-	4.1
Antioxidant	kg	0.25	-	-
Polypropylene	kg	0.55	33.7	
Glass	kg	-	-	89.4
Fuel oil	kg	45	-	-
Water	kg	16300	-	-
Energy	kWh	30	41.8	31.1
Outputs				
Fishmeal	kg	212	-	-
Fish oil	kg	108	-	-
Anchovy paste	kg	-	595	405
Wastewater	kg	608	-	-

Life Cycle Impact Assessment (LCIA)

The software GaBi 6.0 was used in the LCI modelling, whereas the LCIA was conducted with the environmental sustainability assessment (ESA) methodology using the metrics developed by the Institution of Chemical Engineers (IChemE 2002): natural resources (NR) and environmental burdens (EB). NR includes the consumption of energy ($X_{1,1}$) [MJ], materials ($X_{1,2}$) [kg] and water ($X_{1,3}$) [kg] for the considered process/product, and it can be described by an NR dimensionless index X_1.

In relation to the outputs, the environmental impacts were grouped into each environmental compartment: air ($X_{2,1}$) and water ($X_{2,2}$). The following impact categories were considered: atmospheric acidification (AA), global warming (GW), human health (carcinogenic) effects (HHE), stratospheric ozone depletion (SOD), photochemical ozone (smog) formation (POF), aquatic acidification (AqA), aquatic oxygen demand (AOD), ecotoxicity to aquatic life (metals to seawater) (MEco), ecotoxicity to aquatic life (other substances) (NMEco) and eutrophication (EU).

The normalization procedure developed by Margallo et al. (2014b) was applied with the advantage that this methodology provides a complete overview of the environmental performance of the process and simplifies the decision-making process.

To compare the EB to air and water, they were normalised using the threshold values stated in European regulation No. 166/2006 (EC 2006) as weighting factors to obtain dimensionless EB ($X_{2,j,k}^{ref}$). In the NR normalisation process, the average consumption of several canning industries can be used as the reference value ($X_{1,i}^{ref}$).

Equations 1 and 2 show the basic calculations used for the NR and EB normalisation:

$$X_{1,i}^{*} = \frac{X_{1,i}}{X_{1,i}^{ref}} \quad (1)$$

$$X_{2,j,k}^{*} = \frac{X_{2,j,k}}{X_{2,j,k}^{ref}} \quad (2)$$

where i represents different NR (energy, materials and water); j represents different environmental compartments (air, water and land); k represents the environmental impacts to air and water; $X_{1,i}$ is the consumption of each i NR; $X_{1,i}^{*}$ is the normalised value of $X_{1,i}$; $X_{2,j,k}$ is the EB to air and water, and $X_{2,j,k}^{*}$ is the normalised value of $X_{2,j,k}$.

Equations 3 and 4 show the NR dimensionless index (X_1) and the EB dimensionless index to air ($X_{2,1}$) and water ($X_{2,2}$).

$$X_1 = \gamma \alpha_{1,1} X_{1,1}^{*} + \sum_{i=2}^{i=n} \alpha_{1,i} X_{1,i}^{*} \qquad n \in [2,3] \quad (3)$$

$$X_{2,j} = \sum \beta_{2,j,k} X_{2,j,k}^{*} \qquad n \in [1,2] \quad (4)$$

In Equations 3 and 4, $\alpha_{1,i}$ is the weighting factor for the materials and water variables; $\alpha_{1,1}$ is the weighting factor for the energy variable; $\beta_{2,j,k}$ is the weighting factor for EB; and γ is the factor accounting for the energy net importer or exporter character of the plant and has a value of -1 when the plant exports energy and +1 when it imports energy.

RESULTS

Valorisation of heads and spines

Figure 3 shows the main processes contributing to the consumption of natural resources and to the potential environmental impacts for the valorisation of heads and spines.

Figure 3a indicates that the production of fuel and energy had the highest consumption of energy, materials and water. Fuel consumption for steam production generation in the drying step presented the greatest value with a contribution of 88 % of the total energy consuming 2,280 MJ per functional unit. On the other hand, the production of the electricity used during the process had the highest consumption of materials and water, 73 % and 56 %, respectively, whereas the fuel production consumed 18 % of the total materials and 40 % of the total water.

The packaging production made low contributions, under 10 %, and its transport was almost negligible. This is due to the small amount of polypropylene required per functional unit.

In general, the valorisation of heads and spines consumed 14,200 kg of water, 2,600 MJ of energy and 90 kg of materials per functional unit.

With respect to the environmental impacts, Figure 3b shows that, similar to the consumption of natural resources, fuel and electricity production were the least environmentally friendly aspects of the valorisation process. The fuel production for steam generation was the main contributor to the categories of AOD, AA, NMEco, MEco, Eu, GW and POF with contributions between 98 % (NMEco and MEco) and 64 % (GW). This was due to the emissions of heavy metals and organic compounds to water and the emissions of greenhouse gases to air. The production of energy played an important role in SOD (86 %) and AqA (95 %). Finally, the production and transportation of the packaging were insignificant with contributions below 3 % in all impact categories.

The valorisation of 1 t of heads and spines generated 37.8 kg of CO_2 equivalent, which was the main environmental burden, followed by AA with a value of 0.13 kg of SO_2 equivalent. In 2012, the global amount of fishmeal and fish oil produced from fresh fish was 11 million tonnes approximately. If this amount has been produced by fish residues, it was estimated that 270 $\cdot 10^6$ kg of CO_2 equivalent could be saved.

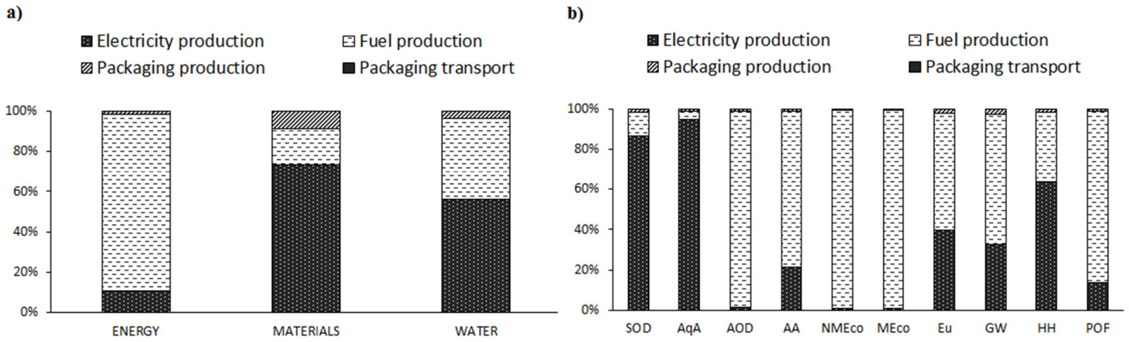

Figure 3. a) Natural resource consumption and b) environmental burdens for the valorisation of heads and spines.

Valorisation of anchovy meat

Figure 4a shows that, in the anchovy meat valorisation, the production of packaging for the pure anchovy paste and anchovy paste with olive oil (polypropylene and glass package) presented the greatest consumption of energy, materials and water. Both processes represented 85 % of the total energy consumption, 95 % of the total material consumption and 86 % of the total water consumption. The production of polypropylene consumed 2,350 MJ of energy, 475 kg of materials and 32,400 kg of water per functional unit, whereas the glass production employed 3,100 MJ of energy, 3,000 kg of materials and 205,300 kg of water.

It should be highlighted that the olive oil production contributed 6 % of the total water, consuming 18,300 kg per functional unit. This is due to the great amount of water used in the irrigation activities of the cultivation stage.

The energy production for the homogenisation and grinding steps consumed 11 % of the total energy, 4 % of the total materials and 7 % of the total water consumed.

The transport of the raw materials such as olive oil and packaging was almost negligible, with contributions below 2 %.

In general, the valorisation of anchovy meat into anchovy paste consumed 64,000 MJ of energy, 3600 kg of materials and 275,700 kg of water.

Figure 4b shows that the production of polypropylene and glass were the key processes relating to potential environmental impacts. The production of polypropylene was the main contributor to AOD (77 %), NMEco (82 %) and MEco (80 %), whereas the glass production was the main contributor to AqA (79 %), AA (84 %), Eu (85 %), GW (77 %), HH (65 %) and POF (77 %). These results are in agreement with Almeida et al. (2015), Iribarren et al. (2010b) and Hospido et al. (2006). Iribarren et al. (2010b) carried out the LCA of fresh and canned mussels from cradle to grave. The results showed that packaging (tinplate) production and transportation was the most significant contributor regarding the canning factories. Similarly, Hospido et al. (2006) performed the LCA of canned tuna using tinplate as packaging material, while Almeida et al. (2015) carried out the LCA of canned sardine using aluminium can. They also identified the production and transportation of the primary packaging as the most important contributor to the potential environmental impacts. Both studies proposed the use of plastic as packaging material to reduce GW impact by 50 %. Moreover, in other studies of LCA food products (Manfredi and Vignali 2014; Humbert et al. 2009) the use of glass jar as packaging also presents the highest environmental impacts due to the weight of the jar and the high energy impact of glass production. The use of recycled glass could reduce the environmental impacts of the product due to the avoided burdens of the production of virgin material. However, these avoided burdens are calculated using the actual mix of virgin and recycled material in the market. The equivalence between virgin and recycled material is based on the efficiency of the recovery process and the substitution factor in the market. The average European market mixes for glass is 55 % virgin material and 45 % recycled material (Bala et al. 2015).

The production of olive oil contributed 18 % and 12 % of the SOD and AqA, respectively, owing to the use of pesticides during the cultivation stage.

The electricity production had a significant contribution to SOD (40 %) and contributed to the remaining categories at percentages between 3 % (NMEco and MEco) and 18 % (HH).

Finally, the percentages contributed by the transport of raw materials (olive oil and package) were below 5 %.

GW was the highest environmental impact associated with the valorisation of anchovy meat with a value of 416 kg of CO_2 equivalent per functional unit. This was mainly due to the emissions of greenhouse gases during the production of polypropylene and glass.

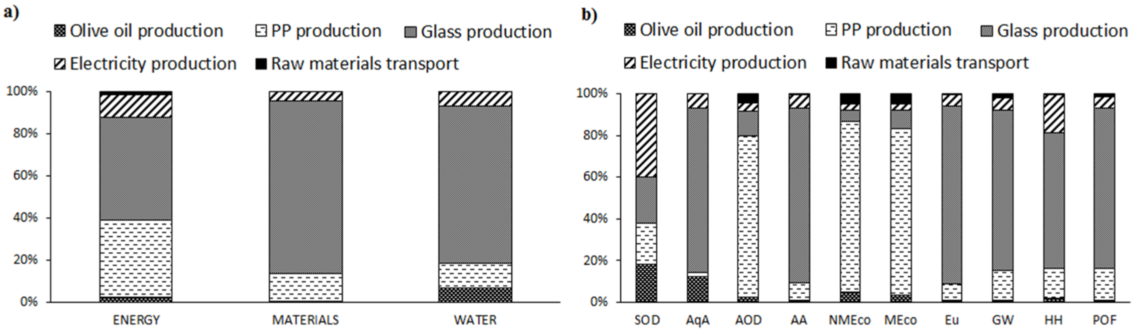

Figure 4. a) Natural resource consumption and b) environmental burdens for anchovy meat valorisation.

Comparison of management alternatives

The aim of this section is to quantify the environmental performance of several wastes management options. The alternatives considered in this work include material valorisation (evaluated in the previous section); incineration with energy recovery and landfilling with biogas recovery and without biogas recovery. These scenarios do not simply offer a waste management service (unlike landfilling without biogas recovery) but also arise as manufacturers. That is to say, marketable products are obtained from the anchovy wastes. These products are then introduced in the market to replace a certain part of the product market demand. In this context, products from valorisation, incineration and landfilling are said to avoid the conventional production of the goods being replaced (system expansion). Consequently, the EB of the conventional processes are also avoided. This is the concept of avoided burdens in LCA. In this case, the production of fishmeal and fish oil from fresh anchovy (including fishing activity) was selected as the technology that replaces the valorisation system for the heads and spines. The production of tuna pâté was chosen as the process replaced in the anchovy meat valorisation. This assumption was based on the work of Iribarren et al. (2010a), which states that products with similar uses and protein content can be substituted in a system expansion. Incineration and landfilling with biogas recovery also involve energy production. Therefore, the electric power mix of Spain included in the ELCD-PE GaBi database was selected as the technology replaced in the system expansion (PE International 2014). Thus, 100 % of the environmental burdens are linked to the corresponding waste management.

Comparison of heads and spines management alternatives

In order to compare the heads and spines management alternatives three scenarios were considered:

- Scenario A1 includes the valorisation of 1 t of heads and spines to produce fishmeal and fish oil assuming the subtraction of the production of 212 kg of fishmeal and 108 kg of fish oil from fresh anchovy as avoided burdens.
- Scenario A2 consists in the incineration of 1 t of heads and spines taking into account the avoided burdens for the production of 1.24 GJ of the corresponding energy according to the Spanish mix.
- Scenario A3 considers the management of 1 t of heads and spines in landfill. Landfilling without gas recovery (Scenario A3b) has been considered as a management service and no marketable product is provided. However, in the case of landfilling with gas recovery (Scenario A3a) it is necessary to consider the production of 132 MJ according to the Spanish mix as avoided burdens.

Figure 5 displays the comparison of the environmental performance of the four scenarios. Both landfilling alternatives (scenario A3a and A3b) were the least environmentally friendly scenarios for all impact categories except for SOD, AOD and HH, which were higher in scenario A2 (incineration). This was due to the cement production for the solidification of fly ash from waste incineration and the consumption and production of urea for flue gas treatment in the incineration process. Moreover, the generation of dioxins during the incineration process was the main contributor to the HH impact category. However, as stated previously, this alternative of management generates energy, a marketable product that considerably reduces the environmental impacts.

Scenario A3a and A3b presented the highest GW values: $8.1\cdot10^{+2}$ and $8.3\cdot10^{+2}$ kg CO_2 eq., respectively. The environmental impacts associated with scenario 3a and 3b were very similar; therefore, the biogas recovery does not have much influence on the environmental performance.

Scenario A1 was the most favourable alternative for management of heads and spines in all impact categories except AA owing to the consumption of fuel oil for steam production. The fuel production generated 0.1 kg of

SO_2 eq. per functional unit because of the emissions of acid compounds, such as ammonia, HCl, HF and SO_2. However, the valorisation of heads and spines allows two products with a high demand in the market to be obtained; in addition, anchovy fishing for the production of fishmeal and fish oil is reduced.

The negative values in Figure 5 are associated with an environmental benefit. In scenario A1, the EB of the production of fishmeal and fish oil from fresh anchovy were higher than the impacts of the manufacture from anchovy wastes. This is due to the high impact of fishing that is avoided in wastes valorisation. Similarly, in scenario A2, the negative values were associated with the energy production from waste combustion.

To obtain a global comparison of the three scenarios, the results were grouped into two impacts: EB to air and EB to water. The highest total impact to air was observed in scenarios A3a and A3b ($1.1\ 10^{-3}$), whereas the valorisation (scenario A1) presented a negative value owing to the avoided burdens. With respect to the water compartment, scenarios A1 and A2 had negatives values, whereas scenario A3 was the worst alternative.

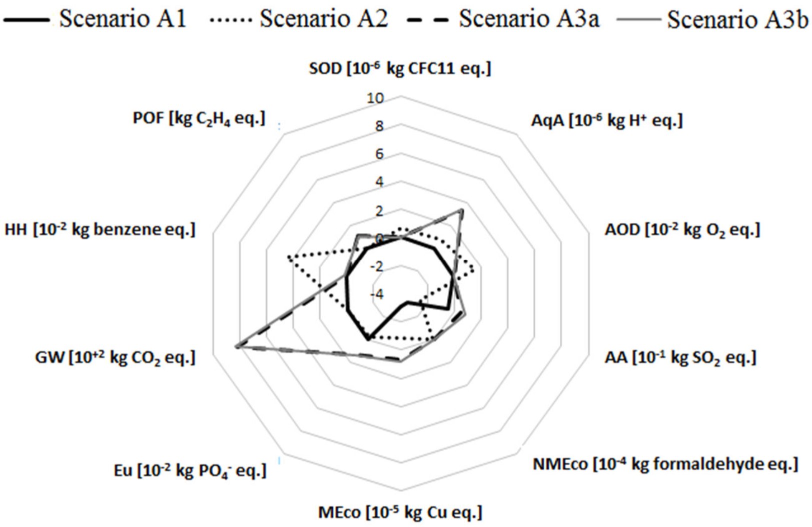

Figure 5. Environmental comparison of four alternative scenarios for anchovy heads and spines management: A1 valorisation, A2 incineration, A3a landfilling with gas recovery, A3b landfilling without gas recovery.

Comparison of anchovy meat management alternatives

In the case of anchovy meat management, three alternative scenarios have been assessed:

- Scenario B1 considers the management of 1 t of anchovy meat to produce 1 t of anchovy paste (with and without oil) assuming the subtraction of the production of 1 t of tuna pâté as avoided burdens.
- Scenario B2 consists of the incineration of 1 t of anchovy meat subtracting the avoided burdens for the production of the 1.24 GJ according to the Spanish electricity mix.
- Scenario B3 considers the management of 1 t of anchovy meat in landfill, taking into account the same considerations of previous section for gas recovery (taking into account the production of 132 MJ of electricity according to the Spanish electricity mix as avoided burdens).

Figure 6 displays the comparison of the environmental performance associated with the four different scenarios. As in the previous case, landfilling had the greatest environmental impacts in all categories except SOD, AOD, and HH, which were higher for incineration (scenario B2), and AA, which was greater in the valorisation alternative (scenario B1). This was due to the production of olive oil for the manufacture of paste and the fabrication of glass for the packaging.

In this case, the negatives values of the EB in scenario B1 were due to the avoided burdens linked to the manufacture of tuna pâté. The EB of the production of tuna pâté was higher than that of the manufacture of paste from anchovy meat.

Likewise, the negative values in scenario B2 were due to the production of energy from the incineration process (avoided burden).

The valorisation of anchovy meat seems to be the best management alternative. Moreover, the anchovy paste has the advantage of being assigned for direct human consumption, replacing other products with a similar protein supply for humans, such as tuna and mussel pâté.

Finally, the results were grouped into EB to air and EB to water. Similar to the previous section, scenarios B3a and B3b featured the highest EB to air and water. Thus, valorisation is the best environmental management alternative.

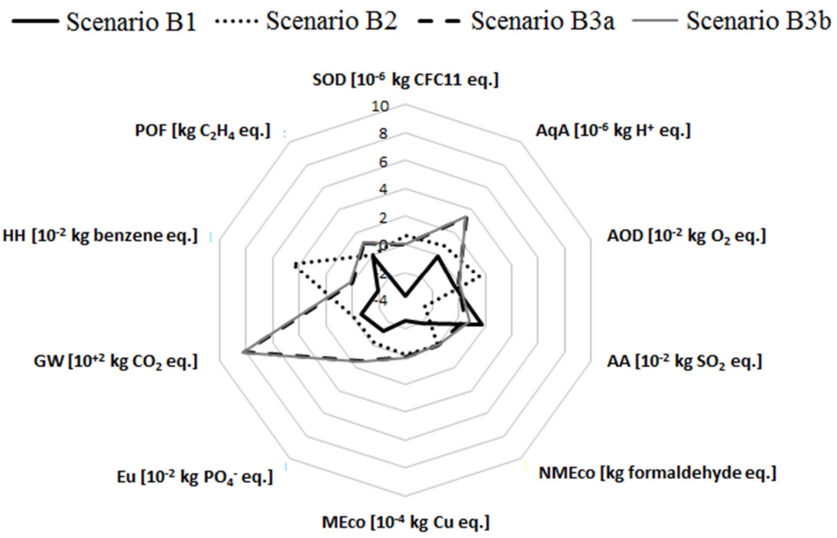

Figure 6. Environmental comparison of four alternative scenarios for anchovy meat management: B1 valorisation, B2 incineration, B3a landfilling with gas recovery, B3b landfilling without gas recovery

CONCLUSIONS

The environmental performance of the treatment and valorisation of anchovy wastes was measured using an LCA tool in this work. Heads and spines can be valorised to produce fishmeal and fish oil. The production of fuel for steam generation in the drying step was identified as the least environmentally friendly process of the valorisation process.

The environmental performance of head and spine valorisation was compared with two alternative scenarios: incineration and landfilling with and without biogas recovery. It was concluded that valorisation featured a better environmental profile than incineration and landfilling. Similarly, the environmental characterisation of anchovy meat valorisation to produce anchovy paste indicated that the production of the package, polypropylene and glass presented the highest consumption of NR and the greatest EB. Packaging is part of the solution to reduce food impacts. Packaging should increase shelf-life ensuring the quality and security of products. Moreover, it should be adapted to the new consumer lifestyles that are demanding more portion sizes packages in order to reduce food waste. Therefore, in the future, packaging innovation and new technologies will play a key role in food waste prevention.

Furthermore, the comparison of the environmental characterisation with the two alternative scenarios, incineration and landfilling, indicated the advisability of valorising anchovy remains to produce anchovy paste. On the one hand, the valorisation of heads and spines avoids the fishing of fresh anchovies to produce fishmeal and fish oil, and it can be used for direct human consumption. On the other hand, the valorisation of the anchovy remains to produce anchovy paste could replace the production of tuna pâté, which has higher environmental impacts.

The use of anchovy wastes as raw material in the manufacture of fishmeal and anchovy paste could improve the environmental performance of the process and reduce the losses of fish. Moreover, this valorisation could increase the economic benefits of anchovy canning plants, providing economic value to food waste and contributing to a circular economy in the anchovy canning industry. Therefore, the LCA methodology presented in this work is a suitable tool to study alternatives under circular economical thinking.

DECLARATION OF CONFLICTING INTERESTS

The authors do not have any conflict of interest to declare.

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