Journal of Cleaner Production xxx (2016) 1–12

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Introducing life cycle thinking to define best available techniques for products: Application to the anchovy canning industry

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ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form
8 August 2016
Accepted 8 August 2016
Available online xxx

Keywords:
Best available techniques
Engraulis encrasicolus
Integrated product policy
Integrated prevention pollution and control directive
Life cycle assessment
Sustainable production

ABSTRACT

This study presents a method based on life cycle assessment to reduce and simplify the decision-making process and to identify the best available techniques of a product. This procedure facilitates the selection of a technical alternative from an environmental point of view and the reduction of emission levels and the consumption of energy and primary resources. This method comprises the following four steps: (i) the identification of the current techniques of a specific product, (ii) the application of a life cycle assessment to determine the hot spots, (iii) the proposal of the best available techniques and (iv) the development of a best available techniques reference document (step not implemented in our case study). The Cantabrian anchovy canning industry is selected as a case study due to the importance of this sector from economic, social and touristic points of view. An entire life cycle assessment of one can of anchovies in extra virgin olive oil is conducted. The results indicated that the hot spots of the life cycle were the production of aluminium cans (for packaging) and extra virgin olive oil and the management of the packaging waste. According to these results, the study proposes several improvements, such as packaging recycling and several best available techniques for the canned anchovy product.

1. Introduction

One of the main challenges of production systems is industrial environmental sustainability and the ability to reduce the consumption of resources and the generation of pollutants and minimise environmental impacts. In the European context, the Integrated Product Policy (IPP) (Commission of the European Communities, 2003) and the Integrated Prevention Pollution and Control (IPPC) Directive (European Commission, 2008) represent a significant shift in the basis of environmental regulations in Europe.

The IPP Directive considers that products cause environmental degradation from their manufacturing, use or disposal. The IPP seeks to minimise these impacts by evaluating all phases of a product's life cycle and taking action where it is most effective. The IPPC Directive, which was derogated by the Industrial Emissions Directive (IED) (European Commission, 2010), is based on an integrated approach, flexibility and public participation and proposes the use of best available techniques (BATs) for the industrial installations that are covered by Annex I of this regulation. To identify BATs for these industrial sectors, the European Commission has prepared BAT reference documents, which are referred to as BREFs (Ibañez-Forés et al., 2013). The selection of BATs is based on technical feasibility, environmental benefits and economic profitability (Bello et al., 2013). However, according to the IPP Directive, a life cycle oriented approach that considers offsite impacts provides a complete environmental overview of the techniques. Life cycle assessment (LCA) is ideally suited to the type of integrated and holistic assessment that is required by the IPPC Directive to assess the different techniques that are being considered as BATs and identify which technique has the lowest 'cradle-to-grave' impacts based on emissions, energy and resource use (Nicholas et al., 2000).

Abbreviations: BAT, Best Available Techniques; BREF, Best Available Techniques reference document; Cr, Ga; Cradle to Gate, EB; Environmental Burdens, EBS; Environmental Burden Sustainability, EoL; End of Life, E-PRTR; European Pollutant and Transfer Register, EVOO; extra virgin olive oil, FU; functional unit, Ga; Ga, Gate to Gate; Ga-Gr, Gate to Grave; LCA, Life Cycle Assessment; LCI, Life Cycle Inventory; LCIA, Life Cycle Impact Assessment; IED, Industrial Emissions Directive; IPP, Integrated Product Policy; IPPC, Integrated Prevention Pollution and Control; NR, Natural Resources; NRS, Natural Resource Sustainability; TWG, Technical Working Group.

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http://dx.doi.org/10.1016/j.jclepro.2016.08.040
0959-6526/

BATs must protect the environment as a "whole" but the IED does not require the use of a full LCA to assess their environmental performance from "cradle-to-grave". This fact means that all life cycle emissions and impacts are not considered, although BATs aim to reduce certain direct and indirect emissions that are related to an installation. Therefore, the identification of environmentally sustainable options among different BAT alternatives is not possible as some impacts may be either missed or underestimated (Ibañez-Forés et al., 2013). LCAs have been successfully applied to identify environmentally sustainable options among different BAT alternatives for several industrial sectors, such as the cement sector (Valderrama et al., 2012), pig meat production industry (González-García et al., 2015) or metal industry (Yilmaz et al., 2015). BATs are applied to processes, and the BREF documents are only available to the processes of the industrial sectors that are included in the IPPC Directive.

For this reason, the use of LCA can aid in the establishment of several improvement measures and the development of a BREF document that includes the entire life cycle of a product (raw materials extraction, production, use and end of life (EoL)).

In recent years, several studies of the use of LCAs for products (Cooper et al., 2005) such as household refrigerators sector (Luglietti et al., 2016) and aluminium windows (Werner (2005)) have been published. Similarly, LCAs analysis for process such as urea process plant (Khan et al., 2002) and coal based power plant (Khan et al., 2004) evaluation and selection are collected in the literature. These methods have been employed in process design and environmental decision-making. The proposed method employs a systematic approach to estimate the environmental impacts that are associated with the life cycle of products and processes and to identify and evaluate opportunities that affect environmental improvements. In this study, we propose a complementary tool for evaluating environmental impacts and proposing BATs for products. This procedure proposes a set of environmental metrics that are stackable; that is, they can be combined (or stacked) to calculate the environmental impact per product unit over a series of processes that comprise a supply chain. The construction of BREF documents for all processes involved in the supply chain of a product is possible (Schwarz et al., 2002).

This procedure is applied to canned anchovies from the Cantabrian Sea (northern Spain). The quality of fresh raw materials and the handmade and traditional manufacture of the semi-preserved product in Santoña (Cantabria, Spain) is world-renowned. The life cycle of one can of Cantabrian canned anchovies has several environmental problems, such as the management of a large amount of solid residues (approximately 60% of anchovy weight is lost) and liquid waste (primarily water and oils) and the high-energy demand of the manufacture of the cans. Some studies have discussed the anchovy canning industry. A Nordic report on the fish processing industry (Tomczak-Wandzel et al., 2015) developed a case study regarding anchovies; this report is based on an inventory of the fish processing industry, which is oriented to a process (industry) instead of a product. Vázquez-Rowe et al. (2012) reviewed the current state-of-the-art of the LCA development in fishery based seafood production systems and concluded that the literature about canned seafood product is limited. Only canned tuna from Galicia (North of Spain) (Hospido et al., 2006) and Ecuador (Avadí et al., 2015) and canned sardines from Portugal (Almeida et al., 2015) have undergone a complete life cycle assessment.

Regarding anchovies, LCAs have been performed by Fréon et al. (2014) in which the Peruvian anchovy fishing is analysed and Avadí et al. (2014b) in which the eco-efficiency of the Peruvian anchovy fleet is measured using LCA + DEA. Moreover, Avadí et al. (2014a) analyse various anchovy products processed in Peru. However, despite the social and economic value of the canned anchovies in the Cantabria Region, no study has collected information about the entire life cycle of this product in order to design and implement local strategies for the sustainable production and consumption of this food product. This paper considers the life cycle thinking by considering all life-cycle stages of Cantabrian canned anchovies (anchovy fishing, production in the caning industry, packaging, distribution, use and end of life). An integrated approach that is based on the LCA method is proposed. In the published BREF documents, the reported LCA results are rare. Instead, data on mass and energy flows are considered (Kropp and Scheffran (2007)). For many products, several BREF documents (fish production, olive oil production, and waste management) are needed to consider all life cycle steps. A review of these documents is especially important for the Cantabrian anchovy canning sector, which is a handmade industry composed of several small and medium enterprises. Therefore, the objective of this study is the selection of BATs for the Cantabrian canned anchovy industry that encompass the life cycle steps for the entire product to provide producers with a simple tool for decision-making.

2. Methods

Fig. 1 shows the proposed method for the development of a BREF document for a product based on the interaction between IPP and IPPC policies. The procedure includes the following four main steps:

1. Identification of current techniques for raw material extraction, manufacture, use and EoL of a specific product.
2. Application of the LCA procedure to determine the environmental impacts and hot spots for the different phases of a product's life cycle.
3. Proposal of BATs for a product life cycle to develop a BREF. The use of BATs enables a reduction in the environmental impact and the selection of the most environmentally friendly alternative.
4. According to previous results, the development of a BREF document for a product.

In this paper, only steps 1–3 were developed. The application of this method to the canned anchovy product will be conducted in a future study to elaborate a BREF document (step 4) for anchovy canning products. Therefore, this paper only proposes some recommendations about BAT for the anchovy canning industry of Cantabria.

2.1. *Identification of the current techniques and estimation of the environmental impacts*

The first stage comprises the state of the art of the main techniques that are applied in the manufacture, use and EoL of a product. A rigorous review of the current situation of the industrial sector is required.

With this information, the input and output data of the system are collected to conduct the LCA. This method determines the environmental metrics for the entire life cycle of the product using an integrated approach. The metrics of the processes in the "cradle-to-gate" (Cr–Ga), "gate-to-gate" (Ga–Ga) and "gate-to-grave" (Ga-Gr) stages are obtained. These metrics are stacked to obtain a set of environmental indicators for a product. The use of stackable units enhances the versatility and usefulness of the method as a decision-making tool to reduce the LCA complexity. The metrics for the entire supply chain of a product can be compared and evaluated (Schwarz et al., 2002).

The environmental metrics that are proposed for the life cycle

Please cite this article in press as: Laso, J., et al., Introducing life cycle thinking to define best available techniques for products: Application to the anchovy canning industry, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.08.040

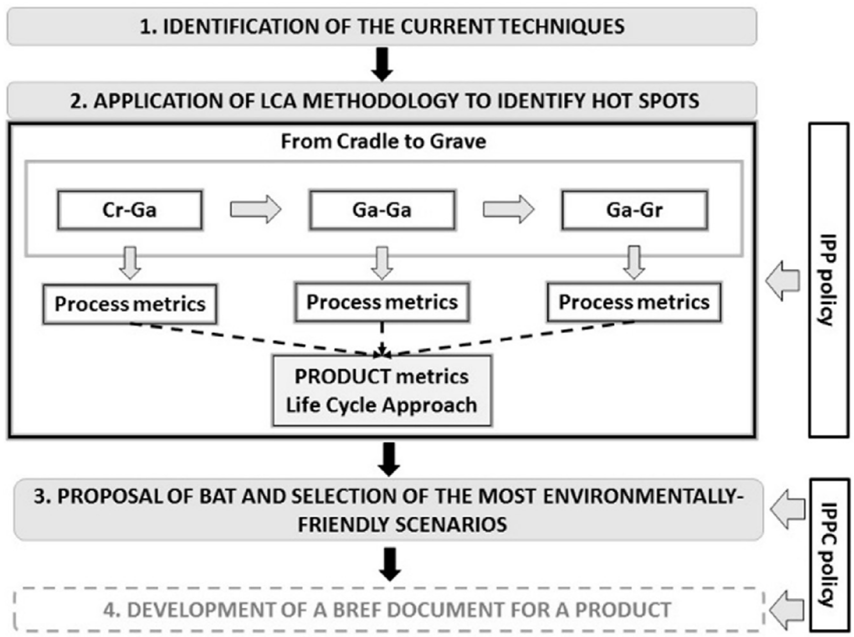

Fig. 1. Life cycle oriented procedure for developing a BREF document for a product. IPP: Integrated Product Policy; IPPC: Integrated Prevention Pollution and Control; Cradle to gate (Cr–Ga); Gate to gate (Ga–Ga); Gate to grave (Ga-Gr); Best Available Techniques (BAT); Best Available Techniques reference document (BREF).

impact assessment (LCIA) are based on the following two main variables: natural resources sustainability (NRS) and environmental burdens sustainability (EBS). NRS includes the consumption of the final useful resources, such as energy ($X_{1,1}$) [MJ], materials ($X_{1,2}$) [kg] and water ($X_{1,3}$) [kg], for the considered process and/or product; thus, it can be described by a NRS dimensionless index X_1 (Margallo et al., 2014). EBS includes the main environmental burdens (EBs) to air and water due to the release of pollutants. This set of indicators, which is proposed by the Institution of Chemical Engineers (IChemE) (IChemE, 2002), can be used to measure the environmental sustainability performance of an operating unit or product, which provides a balanced view of the environmental impact of inputs (resource usage) and outputs (emissions, effluents and waste) (García et al., 2013). They reduce the complexity of the LCA, which improves the comprehension of the results and assists the decision-making process. The environmental impacts were classified into ten variables that were grouped by the release to each of the following environmental compartments: air ($X_{2,1}$) and water ($X_{2,2}$) (Table 1).

Both NRS and EBS are subjected to a normalisation and weighting procedure. Two normalisation methods are typically employed in LCAs, internal and external normalisation. Each of the normalisation methods is based on different methodological principles (Ji and Hong, 2016).

The goal of external normalisation is to analyse the case-specific life cycle impact assessment (LCIA) results using a wider context (Dahlbo et al., 2013) and to transform the LCIA scores to more meaningful scores and reveal the magnitude of the impacts (Myllyviita et al., 2014). Internal normalisation is primarily considered to be an operational prerequisite to weighting (Dahlbo et al., 2013). An internal normalisation was proposed for NRS, whereas an external procedure was applied for EBS.

Internal normalisation or case-specific normalisation involves division by the maximum value (Norris, 2001). The normalised values are obtained by dividing the characterised environmental impacts by a maximum characterised environmental impact of alternatives (Ji and Hong, 2016). Equation (1) shows the basic calculations for the internal normalisation of NRS (Margallo et al., 2014):

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

where i represents different natural resources (NR), including

Table 1
Environmental burdens and reference value for normalisation.

Environmental burdens (EB)		Units	Threshold value (kg/year) (EC, 2006)
$X_{2,1}$	**EB to air**		
$X_{2,1,1}$	Atmospheric acidification (AA)	kg SO_2 eq.	150,000
$X_{2,1,2}$	Global warming (GW)	kg CO_2 eq.	100,000,000
$X_{2,1,3}$	Human health (HHE)	kg benzene eq.	1000
$X_{2,1,4}$	Photochemical ozone formation (POF)	kg ethylene eq.	1000
$X_{2,1,5}$	Stratospheric ozone depletion (SOF)	kg CFC-11eq.	1
$X_{2,2}$	**EB to water**		
$X_{2,2,1}$	Aquatic oxygen demand (AOD)	kg O_2 eq.	50,000
$X_{2,2,2}$	Aquatic acidification (AqA)	kg H^+ eq.	100
$X_{2,2,3,1}$	Ecotoxicity to aquatic life (organics) (MEco)	kg Cu eq.	50
$X_{2,2,3,2}$	Ecotoxicity to aquatic life (metals) (NMEco)	kg formaldehyde eq.	50
$X_{2,2,4}$	Eutrophication (EU)	kg phosphate eq.	5000

energy, materials and water; $X_{1,i}$ is the consumption of each i NR; $X^*_{1,i}$ is the normalised value of $X_{1,i}$ and $X^{ref}_{1,i}$ is the maximum NR, which is assumed to be the reference value.

External normalisation relates to a magnitude of impacts that are caused by an investigated product system on a certain reference value (Myllyviita et al., 2014). The external normalised results are calculated by dividing the characterised environmental impact category by the reference value of the same impact category. A reference system can be selected based on various dimensions: a system basis (e.g., a region and economic sector), spatial scaling (e.g., nation and continent), temporal scaling (e.g., per year) and additional magnitude scaling (e.g., per capita) (Ji and Hong, 2016). In this case, the reference values that were considered for EBS were the threshold values that were included in the European Pollutant and Transfer Register (E-PRTR) regulation (Table 1). The E-PRTR regulation provides information about releases of pollutants that must be reported by facilities that conduct activities that are included in the IPPC Directive (European Commission, 2006a). This regulation includes the threshold values of these pollutants, which can be employed as an important aid in the normalisation process as they provide an overview of the environmental performance of the installation on a European level (Margallo et al., 2014). Equation (2) displays the normalisation procedure of EBS:

$$X^*_{2,j,k} = \frac{X_{2,j,k}}{X^{ref}_{2,j,k}} \tag{2}$$

where j represents different environmental compartments (air and water); k represents the environmental impacts to air and water, as described in Table 1; $X_{2,j,k}$ are the EB to air and water; $X^*_{2,j,k}$ is the normalised value of $X_{2,j,k}$; and $X^{ref}_{2,j,k}$ is the reference value for EBS normalisation.

Weighting is the process of integrating a variety of normalised environmental impacts as a single index by assessing the relative importance of each impact category to the normalised environmental impacts (Ji and Hong, 2016). In this case, the three NRS normalised variables ($X^*_{1,i}$) that represent energy, materials and water consumption and the ten EBS normalised variables ($X^*_{2,j,k}$) are subjected to direct summation. Therefore, the NRS index (X_1) can be assessed according to Equation (3), whereas the calculations of the EBS index to air ($X_{2,1}$) and water ($X_{2,2}$) are based on Equation (4).

$$X_1 = \gamma\alpha_{1,1}X^*_{1,1} + \sum_{i=2}^{i=n}\alpha_{1,i}X^*_{1,i} \quad n\in[2,3] \tag{3}$$

$$X_{2,j} = \sum \beta_{2,j,k}X^*_{2,j,k} \quad n\in[1,2] \tag{4}$$

In Equations (3) and (4), X_1 is the NRS index that includes energy, materials and water consumption; $\alpha_{1,i}$ is the weighting factor for the materials and water variables; $X_{2,j}$ are the EBS indexes for air and water; $\alpha_{1,1}$ is the weighting factor for the energy variable; $\beta_{2,j,k}$ is the weighting factor for EBS; and is the factor that accounts for the energy net importer or exporter character of the plant. The value of the factor γ is -1 when the plant generates energy and $+1$ when the plant consumes energy. Consequently, the NRS index is dependent on the weight that is assigned to each final resource variable. When the three final resources are equally relevant, for each i. This equation is treated as an assumption, as it is the best method for obtaining a single index that enables a comparison across several plants (Margallo et al., 2014).

2.2. Proposal of BAT and elaboration of a BREF document

For any system, an extensive range of candidate BATs exists. Their initial choice will be guided by the IED requirements to target the environmental hot spots that are identified in the LCA stage (Ibañez-Forés et al., 2013).

Once the BAT candidates of a product system are chosen based on technical and environmental criteria, the BREF document may be elaborated. This document contains BAT conclusions and the emission and consumption levels that are associated with the best available techniques.

However, some differences exist between the BREF of a product and a process. In the elaboration of a BREF document for a product, the use of LCA is essential. A continuous exchange of information between the LCA results and the BREF document elaboration occurs. The interaction is performed throughout all LCA stages: definition of the goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation. (Detailed information about the elaboration of a BREF document and the comparison between a BREF document for process and a BREF document for product is available in the supplementary material).

3. Case study: Cantabrian canned anchovy

The method described in Section 2 was applied to determine the environmental impacts and BATs for the life cycle of one can of Cantabrian anchovies.

3.1. Current techniques and LCA of Cantabrian canned anchovies

To determine the current techniques that are applied in the canning sector of the Cantabria region, a technical working group (TWG) was created in 2015. The group was composed of a scientific management team and an advisory team. The Association of the Manufacturers of Canned Fish of the Cantabria Region (Consesa) comprising experts in the field and the Regional Department of the Environment form the latter. The scientific group, which coordinates the work, comprises researchers of the University of Cantabria. The creation of this TWG helped to determine the state of the art of the industrial sector and to collect information to conduct the LCA study. This TWG proposes and discusses the BATs that will facilitate the decision-making process in the canning sector. Fig. 2 describes the members and tasks of the TWG.

The TWG analysed the anchovy canning sector in Cantabria. Consequently, three.

plants from Santoña, which produced in 2014 160,000 kg of canned anchovies, were selected to perform the LCA study from cradle-to-grave. The cradle-to-gate (Cr–Ga) stage included the extraction, production and transport of raw materials (anchovy, oil, salt, and packaging); the gate-to-gate (Ga–Ga) stage comprised the anchovy processing and the waste management, and the gate-to-grave (Ga-Gr) stage covered the distribution, use and end-of-life of the canned anchovies.

According to the objective of this study, the functional unit (FU) was the final product composed by one aluminium can, which contains 30 g of anchovy and 20 g of extra virgin olive oil (EVOO). The emissions, consumptions of materials, water and energy along the life cycle were referred to this FU.

Fig. 3 displays the flow diagram of the study system, in which the construction, production and maintenance of necessary infrastructures and equipment were excluded based on the long estimated lifespan (Avadí et al., 2014a).

Anchovy fishing includes the stages of vessel construction, use, maintenance and EoL of the vessel (Fréon et al., 2014). The canning factory receives the fresh anchovies from the harbour. The fish are

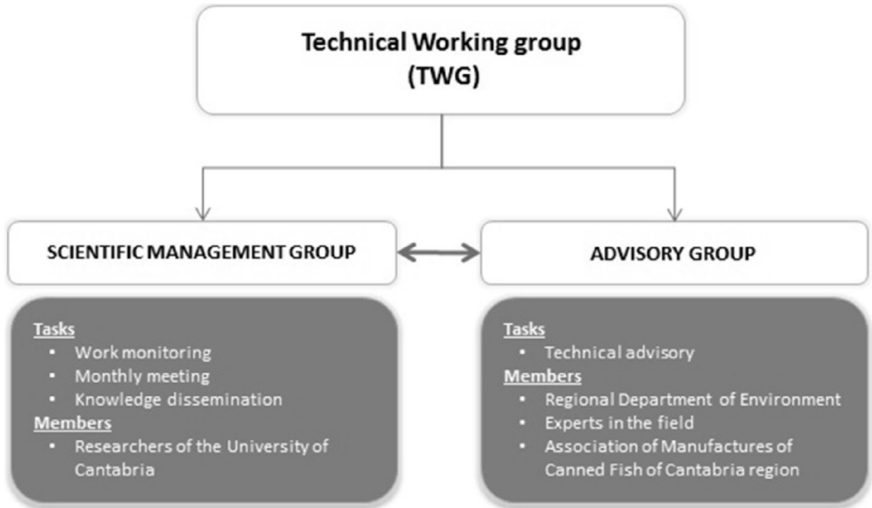

Fig. 2. Description of the technical working group of the canning industry.

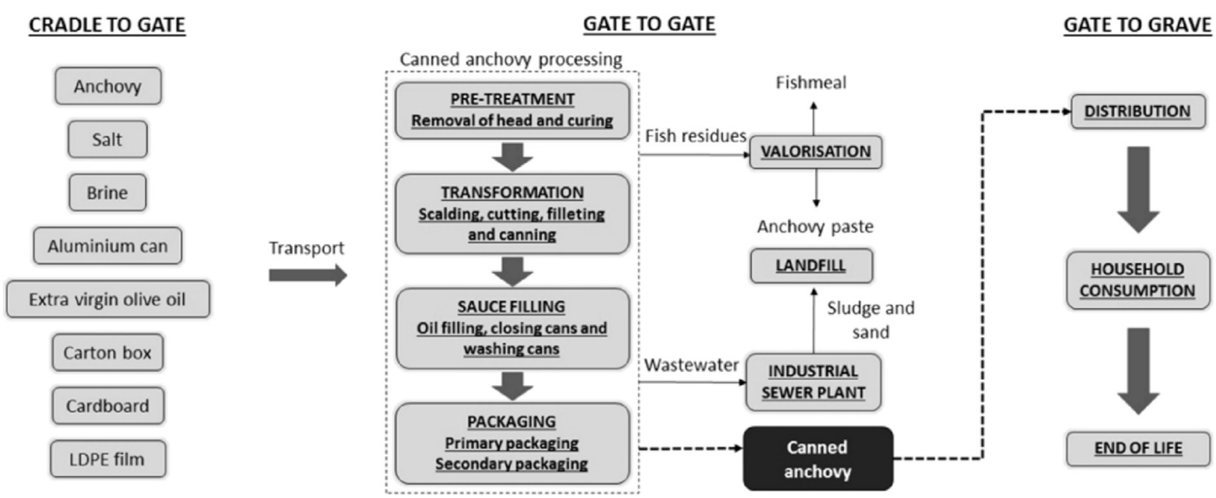

Fig. 3. System boundaries of the life cycle of one can of anchovies.

beheaded and placed in layers with a bed of salt between each layer of fish for six months. After curing, the skin is removed by cold and hot water (scalding), and each anchovy is cut and filleted by hand. The anchovy fillets are packed in cans that are filled with EVOO. The cans are sealed, washed, codified and packed. The primary packaging is composed of the aluminium can and the boxboard. Secondary packaging for the transportation of the final product consists of corrugated cardboard boxes and low-density polyethylene (LDPE) film to wrap the packs.

The anchovy processing generates several types of solid and liquid wastes. Fish residues (heads, spines and remaining anchovies) are valorised to obtain a marketable product and prevent their disposal in a landfill. Heads and spines are converted into fishmeal and fish oil in a fishmeal plant, whereas the remaining anchovies are used to produce anchovy paste in the canning plant. Wastewater is collected in manholes to be sent to a principal water trap. This water trap conducts the wastewater of all canning plants to the industrial sewer plant that is located in the industrial site of Santoña. This installation presents the following steps: pre-treatment (sieving) and physico-chemical treatment. The treated water is discharged through the sewage pipe to the Cantabrian Sea. (The composition of the wastewater that is generated during the canning process is listed in Table S2 in the supplementary material).

After the processing stage, the final product is stored in cold conditions in the canning plant and distributed to wholesale and retail markets. In this study, the canned anchovies were transported from the canning plant to a logistic hub, which was located 40 km from the plant and to a supermarket that was located 10 km from the hub. The semi-preserved product was stored in a refrigerator of a small supermarket in the city centre. The consumption of energy in the supermarket was 2.52 MJ/kg product for a storage time of six days (Büsser and Jungbluth, 2009).

The use step involves the direct action of the consumers throughout the purchase and consumption process, such as vehicle selection to purchase the products, shelf-time in the household or the employed cooking method. Transport to the point of retail to buy the product is assumed to be conducted by car if the purchase is made at superstores or large supermarkets and by foot if the purchase occurs in nearby markets and small shops (Vázquez-Rowe et al., 2013). In this case, consumers who live in the city centre frequent the small supermarket by foot.

At home, the product must be stored in household freezers at a temperature between 5 and 12 °C. Büsser and Jungbluth (2009) report an energy consumption of 2.84 MJ/kg for a storage time of

30 days and 20 kg of cooled products in the refrigerator. Regarding the consumption pattern, canned anchovies are ready-to-eat products; they do not require any cooking. Therefore, the environmental impact of this stage is null.

Regarding the EoL of the canned anchovies, the aluminium cans and the cardboard boxes are disposed of in a landfill.

3.1.1. Data acquisition

3.1.1.1. Primary activity data. Primary data on the anchovy canning process were obtained by a series of questionnaires that were completed by employees of the canning plants of Santoña (Cantabria, Spain). The questionnaires comprised an extensive range of operational aspects, such as the consumption of energy, fuels, water and raw materials (salt, brine, EVOO and packaging materials) and the generation of solid and liquid wastes as principal outputs.

3.1.1.2. Secondary data. Background data regarding the production of the aluminium can, cardboard, corrugated cardboard and LDPE film, the transportation and landfilling were obtained from the databases PE International (PE International, 2014) and Ecoinvent® 3.1 (Frischknecht et al., 2007). These databases are the most robust life cycle inventories on the market with representative data for European conditions. The use of these databases ensures data quality as they are subjected to a thorough review procedure and new updates are continually launched.

The transportation of raw material was performed considering a Euro 4 truck with a maximum total capacity of 28 t, which circulates on a motorway over a longer distance. The emissions that are associated with the use of diesel were calculated using generic data from the PE database. The landfill disposal based on generic data from the PE database includes the construction and maintenance stages and biogas recovery.

The production of EVOO, salt, brine, the specifications of the WWTP and the distribution and use stages were collected from the literature.

Rock salt was employed in this analysis as it is the most utilised type of salt in Europe and its production data are based on the Germany mining sector, whose values are representative of the European average (Onandía, 2016).

To improve data quality and consider the local idiosyncrasy, the electricity mix provided by the PE database was adapted to the characteristics of the Spanish electricity mix of 2014. A bibliographic review of the production of olive oil was performed considering the production of olive oil in Southern Europe. Data on the production of EVOO were obtained from the OiLCA project, which includes data from Spain, Portugal and South France. The OiLCA database was the most complete source, and the system production was the most similar to the production of our oil in Spain (the inventory for the production of 1 L of extra virgin olive oil is included in the supplementary material in Table S2).

In this case, the use of secondary data for the key inputs (EVOO and aluminium can) does not reduce significantly the quality of the life cycle analysis. The quality of the data in the life cycle inventory is naturally reflected in the quality of the final LCA. This quality is established by the following parameters: time-related coverage, geographical coverage and technology coverage (Jensen et al., 1997). Table 2 shows a list of the data sources with their time-related and geographical area coverage.

3.1.1.3. Assumptions

- **Cut-offs**: all material and energy inputs with a cumulative minimum total of 98% of the total mass and energy inputs were included. However, flows that do not satisfy this criterion but are considered to have a significant environmental impact have also been included. Therefore, the production of brine, corrugated cardboard and LDPE film were considered.

- **Transportation:** the capacity of the trucks was chosen considering the most similar options from the database, and the transportation distances were estimated by means of road guides: salt (900 km), brine (80 km), EVOO (850 km) and packaging (270 km).

- **By-products:** the production of canned anchovies involves the generation of anchovy by-products (heads and spines and anchovy meat from remaining anchovies), which can be considered to be a raw material for fishmeal and anchovy pâté production instead of a waste. Therefore, the valorisation of these anchovy residues into marketable products has been included in the study system based on the data from Laso et al. (2016).

- **Aluminium can production:** the production of the aluminium can considers the percentage of recycled aluminium in the market. Based on data from the European Aluminium Association (EAA), the proportion between virgin/recycled aluminium in the market is 63/37%.

3.1.2. Life cycle inventory (LCI)

Table 3 shows the inputs and outputs for the life cycle of one can of anchovies in EVOO. The data represented the average values of three canning plants for 2014.

3.1.3. Life cycle impact assessment (LCIA)

The environmental assessment of the product was performed with the LCA software GaBi 6.0 (PE International, 2014). The LCIA method included the consumption of energy, water and materials and the following environmental impact categories: 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), eutrophication (EU) and non-hazardous wastes (NHW).

Table 4 shows an overview of the total consumption of energy, materials and water of the canning process in the stages of Cr–Ga, Ga–Ga and Ga–Gr.

Cr–Ga presented the highest consumption of natural resources, with a contribution of 65% of the total energy, 68% of the total materials and 97% of the total water consumption. The manufacture and transport of raw materials and primary packaging consumed 2.2 MJ, 0.66 kg of materials and 793 kg of water per functional unit. The Ga–Ga stage, which included all canning process steps, represented 11% of the total energy and 13% of the total materials, whereas the water consumption was 1%. In the Ga-Gr stage, the consumption of water was very low, with a contribution below 2%, whereas the consumption of energy and materials were 21% of the total and 18% of the total, respectively.

Fig. 4 shows the consumption of natural resources for each process in the Cr–Ga, Ga–Ga and Ga–Gr stages.

In the Cr–Ga stage, the production of aluminium cans and EVOO controlled the consumption of natural resources. The production of aluminium cans was the main hotspot of the stage with a contribution of 77% of the total energy, 83% of the total materials and 99% of the total water. These values were primarily related to the production of virgin aluminium, which requires 41.21 MJ of primary

Table 2
Data sources for life cycle inventory of Cantabrian canned anchovy.

Element	Data source	Period	Geographic area
Materials			
Fresh anchovy	Fréon et al., 2014	2014	Peru
Salt	Goetfried et al., 2012	2012	Germany
Brine	NYSDEC, 2015	2013	USA
Extra virgin olive oil	SUDOE, 2011	2011	Europe
Aluminium can	PE database	2012–2015	Europe
Cardboard	PE database	2012–2015	Europe
Corrugated board	Ecoinvent® 3.1	2014	Europe
Polyethylene	PE database	2012–2015	Europe
Transportation			
Truck 28 t	PE database	2005–2012	Europe
Waste treatment			
Wastewater treatment plant	Pasqualino et al., 2009	2009	Spain
Landfill disposal	PE database	2012–2015	Europe
Distribution			
Logistics	CEOE, 2013	2007–2013	Cantabria
Supermarket refrigeration	Büsser and Jungbluth, 2009	2009	Germany
Use			
Home refrigeration	Büsser and Jungbluth, 2009	2009	Germany
End of life			
Landfill disposal	PE database	2012–2015	Europe

Table 3
Life cycle inventory for a can of Cantabrian canned anchovy.

	Input/output data	Units	
Pre-treatment			
Inputs	Fresh anchovy	kg/FU	$9.60 \cdot 10^{-2}$
	Salt	kg/FU	$5.30 \cdot 10^{-2}$
	Brine	m^3/FU	$7.86 \cdot 10^{-6}$
	Energy	MJ/FU	$6.98 \cdot 10^{-4}$
Outputs	Anchovy to transformation	kg/FU	$7.80 \cdot 10^{-2}$
	Solid fish residues (heads and guts)	kg/FU	$1.70 \cdot 10^{-2}$
Transformation			
Inputs	Anchovy from pre-treatment	kg/FU	$7.80 \cdot 10^{-2}$
	Brine	m^3/FU	$4.63 \cdot 10^{-5}$
	Energy	MJ/FU	$3.31 \cdot 10^{-2}$
	Water (scalding)	m^3/FU	$9.26 \cdot 10^{-5}$
Outputs	Anchovy to sauce filling	kg/FU	$3.00 \cdot 10^{-2}$
	Solid fish residues (cutting and spines)	kg/FU	$4.80 \cdot 10^{-2}$
	Wastewater (from scalding)	m^3/FU	$9.26 \cdot 10^{-5}$
Sauce filling			
Inputs	Anchovy from subsystem 2	kg/FU	$3.00 \cdot 10^{-2}$
	Extra virgin olive oil	kg/FU	$2.90 \cdot 10^{-2}$
	Energy	MJ/FU	$1.85 \cdot 10^{-2}$
	Water (washing cans)	m^3/FU	$5.66 \cdot 10^{-6}$
Outputs	Anchovy to subsystem 4	kg/FU	$3.00 \cdot 10^{-2}$
	Wastewater (from washing cans)	kg/FU	$5.66 \cdot 10^{-6}$
	Extra virgin olive oil	kg/FU	$8.97 \cdot 10^{-3}$
Packaging			
Inputs	Anchovy from subsystem 3	kg/FU	$3.00 \cdot 10^{-2}$
	Aluminium can	kg/FU	$1.50 \cdot 10^{-2}$
	Cardboard	kg/FU	$5.00 \cdot 10^{-3}$
	Corrugated board	kg/FU	$2.00 \cdot 10^{-3}$
	Plastic (LDPE)	kg/FU	$1.20 \cdot 10^{-4}$
	Energy	MJ/FU	$7.20 \cdot 10^{-4}$
General consumptions			
Inputs	Water (for general cleaning)	m^3/FU	$3.99 \cdot 10^{-4}$
	Energy (for plant illumination)	MJ/FU	$6.19 \cdot 10^{-2}$
	Natural gas	m^3/FU	$1.47 \cdot 10^{-3}$
Outputs	Wastewater (from general cleaning)	m^3/FU	$3.99 \cdot 10^{-4}$
Distribution			
Inputs	Energy	MJ/FU	$12.60 \cdot 10^{-2}$
Use			
Inputs	Energy	MJ/FU	$14.20 \cdot 10^{-2}$

Table 4
NRS for the life cycle of one can of Cantabrian anchovies.

	Energy (MJ)	Materials (kg)	Water (kg)
Cradle to gate	2.20	0.66	793
Gate to gate	0.37	0.13	8.96
Gate to grave	0.72	0.18	16.2
Total	3.38	0.96	819

energy, $8.32 \cdot 10^4$ kg of water and 4.75 kg of bauxite per kilogram of aluminium. EVOO was the ingredient with the highest consumption of natural resources, with a contribution of 10% of the total energy, 10% of the total materials and 1% of the total water. The manufacture of EVOO is divided into the following two stages: cultivation and processing. Processing presented the highest consumption of NR. Farming required 0.03 MJ of electricity per litre of EVOO, whereas the processing stage required 2.71 MJ per litre. However, 79% of the total consumption of water was employed in the irrigation of olive plants. Regarding the remaining ingredients, the rock salt extraction had a contribution of 9% to the total consumption of materials due to the energy requirements.

The consumption of NR in the extraction, transport and production of brine and secondary packaging (corrugated cardboard and LDPE) was very low. The contribution of transport was low due to the small distances and load. The anchovy capture also had low values of natural resource consumption below 3% as the relative amount of fresh anchovies per FU was very small. Furthermore, this low contribution is underestimated because the Peruvian fishery used as a proxy of the Cantabrian fishery is the most efficient purse-seiner industrial fishery worldwide regarding fuel use (Fréon et al., 2014).

In the Ga–Ga stage, the auxiliary services, that is, the use of electricity of the plant and cleaning of the installations (machines and working areas), presented the highest consumption of energy and water, with contributions of 74% and 61%, respectively, to the total. The transformation step, in particular the scalding process, had a significant consumption of energy (19%) and water (20%). The oil filling step employed 15% of the total energy and 15% of the total water, and the valorisation of anchovy residues presented negative values of consumption of NR due to an environmental benefit. The valorisation of the anchovy residues reduced 23% the energy consumption, 32% the materials consumption and 40% the use of water.

Concerning the materials, the anchovy transformation had the highest consumption (61%) due to the demand of salt and brine in the scalding process. The second greatest consumption was the use of salt for the curing process in the pre-treatment step that

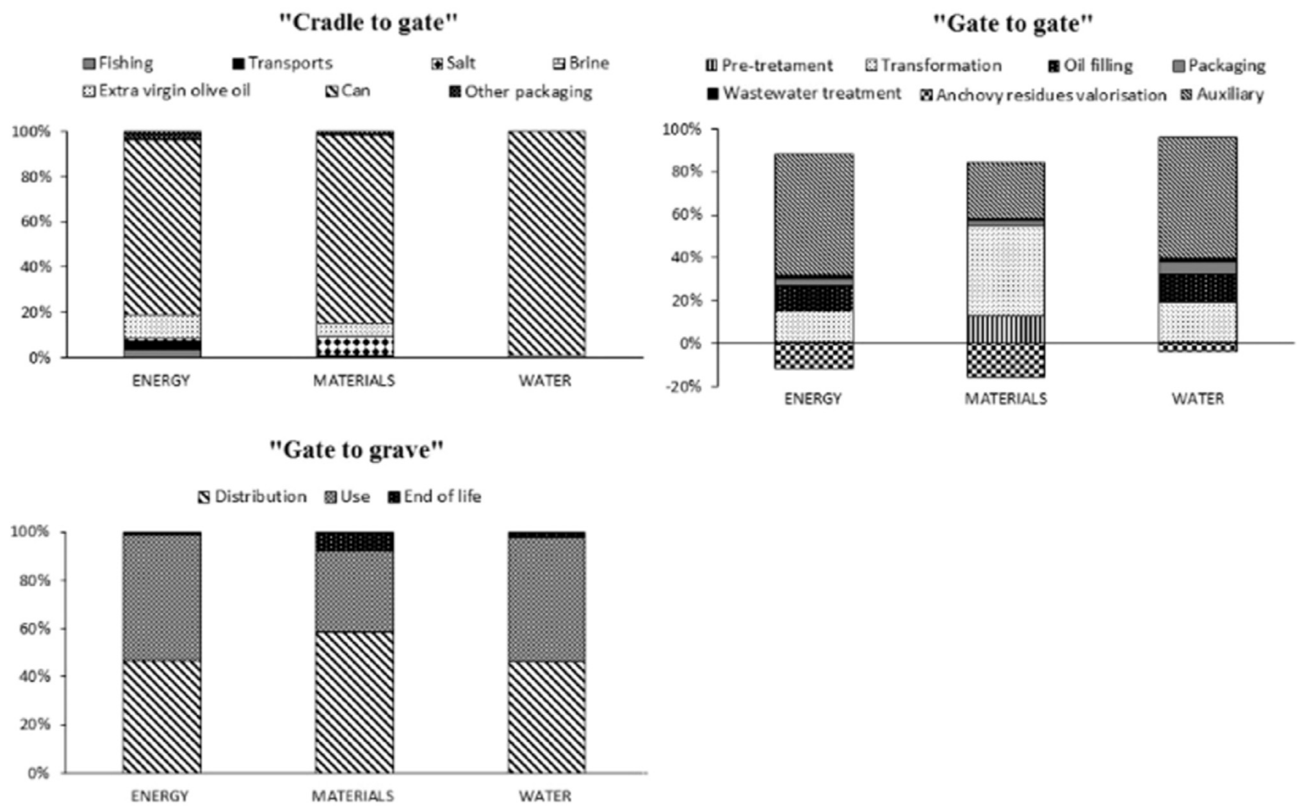

Fig. 4. Contribution of each process to the consumption of NR.

employed 19% of the material resources. The wastewater treatment and packaging steps had a very low consumption of energy, water and materials.

Regarding the Ga-Gr stage, 47% of the total energy and water consumption was attributed to the distribution, whereas the remaining 52% was attributed to the canned anchovy refrigeration in the use step. The consumption of materials and water exhibited a similar trend; in this case, the EoL had a contribution of 8% of materials due to the maintenance of the landfill.

Concerning the EB, the categories with the highest environmental impact were GW ($1.78 \cdot 10^{-1}$ kg CO_2 eq./FU) and HHE ($8.92 \cdot 10^{-3}$ kg benzene eq./FU) due to the emissions of greenhouse gases, such as carbon dioxide, nitrogen oxides and methane (CO_2, NOx, CH_4), and heavy metals in the aluminium can production.

Fig. 5 shows the EB of air and water of each process in the Cr–Ga, Ga–Ga and Ga–Gr.

Similar to the consumption of NR, in the Cr–Ga step, the manufacture of aluminium cans and EVOO were the hot spots that controlled the impacts in almost all categories. The production of aluminium cans had the highest values in AA, GW, HHE, POF, SOD, AOD, NMEco and EU, with a contribution between 52% (SOD) and 99% (HHE). For AqA, the production of secondary packaging had a higher impact, with a percentage of 88%. This finding was attributed to the emissions of sulphuric acid (H_2SO_4), hydrochloric acid (HCl), hydrogen fluoride (HF) and acetic acid in the manufacture of corrugated cardboard and LDPE film. Regarding EVOO, the manufacture of this ingredient presented a small contribution (approximately 6%) to the categories of AA, GW, POF and SOD. The production and use of fertilisers and pesticides for the olive tree growth were the most significant contributors to these impacts.

In the Ga–Ga stage, the use of auxiliary services (electricity and water) was the main contributor in some categories. The generation of electricity and the use of tap water required for the functioning of the plant were the most important contributors to AA (59%), GW (61%), HHE (60%), POF (75%) and EU (67%). The majority of the electricity was employed in the refrigeration of anchovies. During the curing, which requires four to six months, anchovies require refrigeration at temperatures between 3 and 5 °C. The final product is conserved in refrigerators until it is transported. The management of anchovy residues presented negative contributions in all impact categories due to the avoided burdens associated with the production of a fishmeal, fish oil and anchovy paste from anchovy residues.

In the Ga-Gr stage, the distribution and use of the final product presented the greatest environmental impact in all categories, with the exception of POF and AqA, which was attributed to the emissions of organic compounds to air and the generation of acid effluents from leachates of the landfill. The product distribution had a significant impact on AA, GW, HHE, SOD, AOD MEco, NMEco and EU with contributions from 26% (GW) to 47% (SOD). Similarly, the environmental impact of the use step ranged from 28% (GW) to 53% (SOD). The EBs were generated by the refrigeration of the semi-preserved product in the supermarket and at home, and to a lesser extent, the production of diesel for the transportation in the distribution step.

The net weight of anchovy in the can is low (30 g) compared to other similar canning products in Spain or elsewhere (60–100 g), as for instance in the standard "1/4 club" cans. It certainly increase the ratio can weight/fish weight and even more, the ratio olive oil weight/fish weight. Fig. 6 compares the value of GW per kilogram of product, the olive oil/fish ratio and packaging/fish ratio of Cantabrian canned anchovies with other similar works. The values of GW were collected from Avadí et al. (2015) in which the FU was 1 kg of product, therefore, to make the comparison, we have modified our

Please cite this article in press as: Laso, J., et al., Introducing life cycle thinking to define best available techniques for products: Application to the anchovy canning industry, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.08.040

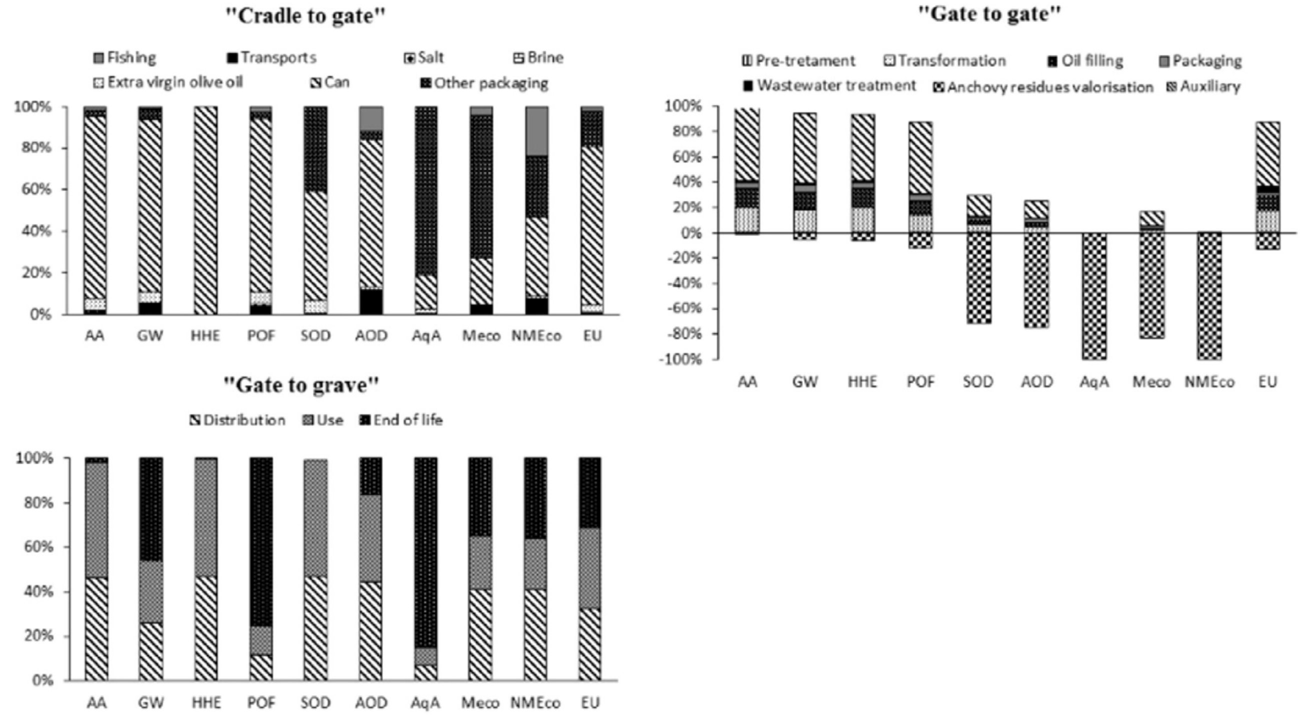

Fig. 5. Contribution of each process to the environmental burdens. AA: atmospheric acidification; GW: global warming; HHE: human health effects; POF: photochemical ozone formation; SOD: stratospheric ozone depletion; AOD: aquatic ozone depletion; AqA: aquatic acidification; MEco: ecotoxicity to aquatic life (organics); NMEco: ecotoxicity to aquatic life (metals); EU: eutrophication.

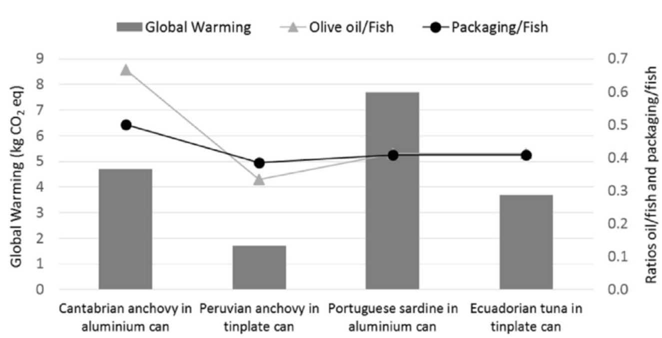

Fig. 6. Comparison of GW per kilogram of product, olive oil/fish ratio and packaging/fish ratio of Cantabrian anchovy, Peruvian anchovy (Avadí et al., 2014a), Portuguese sardine (Almeida et al., 2015) and Ecuadorian tuna (Avadí et al., 2015).

FU. Cantabrian anchovy presented higher GW than Peruvian anchovy. This was due to several reasons: (i) the ratios oil/fish and packaging/fish were higher for Cantabrian anchovy, that is to say, the amount of oil and packaging per kilogram of fish was higher; (ii) Cantabrian canned anchovies used aluminium cans; and (iii) the production of EVOO and aluminium cans were the least environmentally friendly steps of the life cycle of canned anchovies. Canned products that use aluminium can as packaging presented higher GW than those that use tinplate can. These results confirm the requirement to improve the production and management of packaging, discussed in the next section.

3.2. Proposal of BAT for the anchovy canning product

The LCA results indicated that the manufacture of aluminium cans and, to a lesser extent, the production of EVOO were the main hot spots of the Cr–Ga stage.

Therefore, a measure that may improve the environmental performance of the process is the substitution of the primary packaging. Concerning the use of oil in the product, canned anchovies in sunflower oil are also available on the market. The use of sunflower oil tripled the total environmental impact of the product. The high water consumption of the sunflower cultivation step prevented the proposal of this measure as a BAT.

However, an improvement opportunity may be the increase of the efficiency of the oil filling process.

The recycling of the aluminium cans and cardboard boxes after the use phase may improve the environmental profile of this stage. From a life cycle perspective, this section assessed several improvement actions to determine the influence of (i) recycling aluminium cans and cardboard boxes and (ii) the use of different primary packaging materials (aluminium, tinplate, plastic, glass and recycled aluminium).

3.2.1. Management of the packaging waste

The recycling process serves as a waste treatment process for the discarded product and simultaneously produces a new material to be used in a subsequent product (van der Harst et al., 2015). Waste recycling is a multifunctional process that is typically handled by system expansion, and if expansion is not possible, mass or economic allocation can be applied (ISO, 2006). In this study, a system expansion was conducted by considering that the recycled material can completely substitute virgin material on a 1:1 ratio. In these processes, it is referred to as a "closed-loop recycling system". Therefore, the results were based on 100% of the recycling rate of the product for both Al and cardboard. Due to the efficiency of the recycling processes, the material losses were considered to be 5% for aluminium and 10% for cardboard.

The data for the aluminium and cardboard recycling were obtained from Leroy (2009) and Wang et al. (2012), respectively.

Fig. 7 shows an important reduction in the EBs to air and the EBs to water of the canned anchovies when the EoL step comprised recycling instead of landfilling. The EB to air decreased by 95%, whereas the EB to water was nearly reduced by 50%. Aluminium recycling prevents the impact of waste landfilling and the production of virgin aluminium and virgin cardboard, which are high-energy demand processes.

3.2.2. Substitution of packaging materials

In the sensitivity analysis, the aluminium can was compared with other packaging materials, such as tinplate, plastic and glass. According to the results of the previous section, recycled aluminium was included in this comparison. Specifically, aluminium is one of the most recycled packaging materials, at a rate of 57% in Europe (Almeida et al., 2015). The background data for the LCI were obtained from the PE database (PE International, 2014).

Fig. 8 shows the EB to air and EB to water for the use of aluminium, recycled aluminium, tinplate, plastic and glass as packaging materials for the anchovy can. The comparison was made considering that the packaging contained the same amount of product and that the type of transport of the packaging and distances to the canning plant were identical in all cases. In a comparison of EB of several packaging of anchovy products, such as the use of the glass jar, aluminium can or tinplate, the weight of the product provides an inaccurate perception of the environmental impact. In this paper, however, the use of this index is only used to determine the amount of materials that are required for a single product. This index was not included in the packaging material comparison.

The aluminium presented the greatest EB to air and water. The total EB to air was 80 times lower when tinplate was employed, which is approximately 100 times lower when plastic and glass were employed and 17 times lower when recycled aluminium was employed. In the water compartment, the glass and recycled aluminium yielded the lowest environmental impact 50 times lower than the aluminium. The tinplate generated the highest quantity of non-hazardous wastes, as it had the greatest amount of material per functional unit.

Similar results were obtained in other studies, such as Almeida et al. (2015), in which the use of tinplate cans and plastic packaging, instead of aluminium, reduced the GW by half. Hospido et al. (2006) reported that the use of plastic bags instead of tinplate cans decreased the GW and the acidification potential (AP) by more than half. Despite the implementation of this alternative for tuna packaging, this alternative does not seem feasible for anchovies because anchovies and other canned products, such as sardines, are canned to conserve their fish-like shape (Vázquez-Rowe et al., 2014).

According to the results of this study, the use of glass and plastic would improve the environmental performance of the product. The

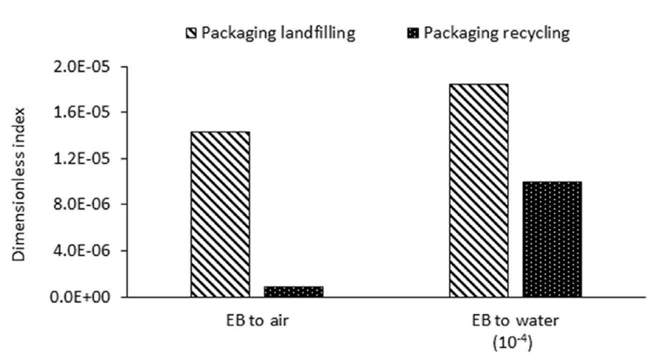

Fig. 7. Comparison of EB to air and water of packaging waste landfilling and recycling.

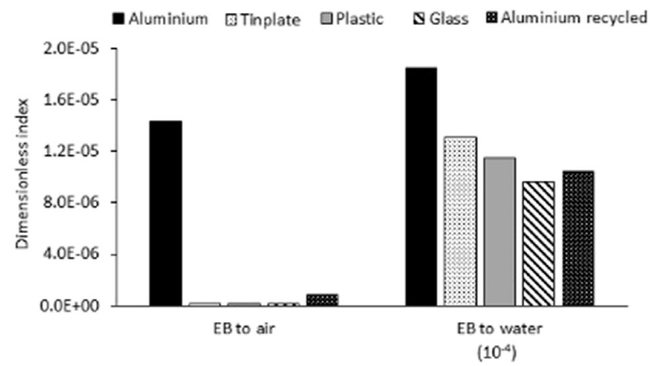

Fig. 8. Comparison of EB to air and water of several packaging materials, including aluminium, recycled aluminium, tinplate, plastic and glass.

use of a glass packaging for this gourmet product is extensively applied despite the increase in the final price. Anchovies with glass packaging must be kept in a cool place away from direct light for extended periods. This type of packaging enables light to pass through the material and oxidises the product.

The use of a plastic can cause non-acceptance of the product as it may decrease the quality of the canned product. Therefore, a balance must be achieved between the eco-design and the customer's perception.

The use of recycled aluminium is already applied in the beverage sector. The body of the aluminium cans is composed of 90% recycled aluminium and 10% primary aluminium, with the lid completely composed of primary aluminium. The metals are characterised by metallic bonding, which provides distinct structures and properties. This type of bonding is not affected by melting; thus, metals can be recycled many times. Therefore, primary metal production only fills the gap between the availability of a secondary material and total market demand (Detzel and Mönckert, 2009).

Both evaluated strategies have demonstrated a beneficial performance for the environment. However, consumers in Spain are not very keen on changing food habits and, in particular, a gourmet product such as canned anchovies are linked to aluminium cans. Consequently, an important marketing campaign is necessary to produce these results for all stakeholders involved (Hospido et al., 2006).

In addition to these improvements, Table 5 collects several candidate techniques for BATs to enhance the environmental profile of the canned anchovies.

The proposal of these BATs lay the foundations to elaborate a BREF document that includes all life cycle stages of one can of Cantabrian anchovies. Despite the existence of a BREF document for the Food, Drink and Milk (European Commission, 2006b), it is extremely large and diverse and contains subsector sections that are rather short, thus, obtaining particular data regarding the techniques and processing of the fish cannery subsector (Barros et al., 2009). The objective of this paper is not an elaborate BREF document about the anchovy canning industry but the selection of BATs for the Cantabrian canned anchovy, which considers the entire product life cycle management and subsequently provides producers with a simple tool for decision-making.

4. Conclusions

This study proposes a method based on LCA for determining BATs for the Cantabria canned anchovy that considers the management of the entire product life-cycle, which provides producers with a simple tool for decision-making. This objective is framed

Table 5
Proposal of BAT candidates for Cantabrian canned anchovies.

	Process stage	Technique	Environmental aspect
Cr–Ga	Raw materials	Maintain an accurate inventory of inputs and outputs at all stages of the process to prevent purchasing unnecessary materials	Energy, materials and water consumption
		Consider the use of other materials for packaging: plastic, tinplate, glass, recycled aluminium	
	Transport	Assess vehicle's conditions	Emissions of combustion gases
Ga–Ga	Transformation	Use filtered recirculated scalding water for preliminary fish rinsing	Water consumption
	Sauce filling	Use of a recovery oil system by recirculation to prevent oil loss	Raw materials consumption
		Recycle process water to wash cans	Water consumption
	Packaging	Collect packaging material and send it to the authorised manager	Raw materials consumption
		Use of recycled cardboard	
	General consumption	Minimise the use of water, energy and detergents	Energy and materials consumption
		Use low consumption lamps	
		Turn off machines when they are not in operation	Wastewater and waste generation
	Solid residues treatment	Separate heads and spines from anchovy meat to be valorised	
	Wastewater treatment	Quantify the water consumption of each area of the canning plant by installing partial accountants	Wastewater generation
		Dry cleaning to reduce the consumption of water and its pollutant load: removal of all possible solid residues prior to the cleaning operations	
		Follow a strict cleaning protocol	
Ga–Gr	Distribution	Assess of vehicle's conditions	Emissions of combustion gases
	End of life	Recycle aluminium cans	Emissions to air, water and land
		Recycle cardboard boxes	

within a project that pursues the sustainability of the Cantabrian anchovy canning sector by applying local strategies to attain the global sustainability of this sector.

Once the current techniques are applied to an entire life cycle of one can of anchovies, the environmental profile was obtained. The study demonstrated that the production of cans and EVOO were the hot spots. The manufacture of aluminium cans represented 58% of the total energy, 61% of the materials and 93% of the consumed water. It is the main contributor to the majority of the air and water categories.

According to these results, some improvement measures were proposed: the recycling of the aluminium cans and cardboard boxes and the substitution of the packaging material. The recycling of the aluminium cans and cardboard boxes decreased the EB to air by 95% and the EB to water by 50%. Consequently, the use of recycled aluminium as a packaging material was evaluated. The results indicated that glass, plastic and recycled aluminium as primary packaging materials reduced the EB to air by approximately 95% and the EB to water between 40 and 50%. However, other considerations, such as the acceptance among consumers and the taste, preservation, quality and price of the final product should be considered. Therefore, a balance among social, economic and environmental considerations must be reached. In addition to these actions, other improvement measures were proposed. The evaluation of these BATs will be conducted in a future study to elaborate a thorough BREF document for anchovy canning products.

This method helps the decision-making process in the ecodesign of food products and can be used by other industrial sectors to facilitate the decision-making process for specific products. Likewise, it facilitates the manufacture of more sustainable products and the development of ecolabels that inform consumers about more sustainable consumption and production habits. This procedure promotes the concept of a circular economy by the valorisation of waste along the supply chain of the product. “Closing the loop” of the product lifecycle via greater recycling and reuse is the basis of the Circular Economy Strategy, which will create economic and environmental benefits to the Cantabrian canning industry, which enables the implementation of local strategies for a global development.

In addition, it represents the first step towards Product Category Rules (PCR) and Environmental Product Declaration (EPD) according to the “European Single Market for Green Products Initiative”, which establishes the following two methods for measuring a product's environmental performance throughout its lifecycle: the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF).

Acknowledgements

The authors thank the Ministry of Economy and Competitiveness of the Spanish Government for their financial support via the project GeSAC-Conserva: Sustainable Management of the Cantabrian Anchovies (CTM2013-43539-R) and to Julia Celaya for her technical support. Jara Laso thanks the Ministry of Economy and Competitiveness of Spanish Government for their financial support via the research fellowship BES-2014-069368. Pere Fullana y Alba Bala thanks the UNESCO Chair in Life Cycle and Climate Change.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2016.08.040.

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Please cite this article in press as: Laso, J., et al., Introducing life cycle thinking to define best available techniques for products: Application to the anchovy canning industry, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.08.040