Finding an economic and environmental balance in the value chains based on circular economy thinking: an eco-efficiency methodology applied to the fish canning industry

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Abstract

Nowadays, the production of food which are environmentally-friendly with the ecosystem and present high economic return is one of the main concerns of the food industry. The eco-efficiency links the environmental performance of a product to their economic value. In this context, this study combines life cycle assessment (LCA) and life cycle costing (LCC) to propose a two-step eco-efficiency methodology assessment for the fish canning industry. An eco-label rating system based on a descriptive weighting of environmental (Global Warming Potential, Acidification Potential, Eutrophication Potential and ReCIPE Single Score Endpoint) and economic (Value Added) indicators is applied to the canned anchovy. Secondly, LCA-LCC results are coupled to linear programming (LP) tools in order to define a composite eco-efficiency index. This approach enables the translation into economic terms of the environmental damage caused when a given alternative is chosen. In particular, different anchovy origins (Chilean/Peruvian, Argentine and Cantabrian) and related waste management alternatives (landfill, incineration and valorization) were evaluated under this cradle to gate approach.

Results indicated that substantial differences can be observed depending on the anchovy origin. Cantabrian scenario shows higher added value score at the expense of larger environmental impacts. Moreover, its environmental scores are lowered when fish residues are valorized into marketable products, while increasing the valued added.

This study demonstrates the environmental and economic benefits of applying circular economy. According to this, it is possible to introduce the cradle-to-cradle concept in the fish canned industry. The methodology proposed is intended to be useful to decision-makers in the anchovy canning sector and can be applied to other regions and industrial sectors.

1. Introduction

In the last years, the transition toward more efficient resource production and consumption patterns has been one of the main challenges for governmental authorities due to the possible consequences for the human well-being, the economy and the environment (Huysman et al. 2015). In this context, the European Commission (EC) launched the initiative “The Roadmap to Resource Efficient Europe” (EC, 2011) that proposes ways to increase resource productivity and to decouple economic growth from resource use and its environmental impact.

In particular, over the past century, the worldwide marine fishery resources have been increasingly subjected to overexploitation, detrimental fishing practices and environmental degradation (FAO, 2009), and intense fishing pressure has led to a precipitous decline of several fish stocks (FAO, 2016). Moreover, the growth of the world population translates into an increase in the consumption per capita of fish and seafood. In fact, it is estimated that 31.4% of fish stocks are being fished at a biologically unsustainable level (Bonanomi et al. 2017). Since fish and seafood supply nearly 17% of the world´s animal protein intake and are increasingly recognized as being an important part of global food security, a food versus feed debate exists. Controversies exist over what the best use of fish is, i.e., for either direct human consumption (DHC of food fish) or indirect human consumption (IHC or feed fish) through the feeding of farmed animals (Fréon et al. 2014b). At a global scale, it is estimated that approximately a third of landed fish catches were used for animal feed in recent years. The ratio IHC/DHC depends on cultural and geographical aspects as well as the fish species. This is clear for anchovies species. In Peru, approximately 98% of total anchoveta (*Engraulis ringens*) landings are destined to fishmeal and fish oil industry. This sector produced on average (2006-2015) 1,183 million t/year of fishmeal and 230,000 t/year of fish oil (Fréon et al. 2017). Contrariwise, in Spain, almost 100% of the captured anchovy (*Engraulis encrasicolus*) is destined to DHC, either as fresh anchovy (50%) or as elaborated products, such as salted or canned anchovies (50%) (Laso et al, 2016b).

One of the most recognized anchovy-processing sector in Spain is located in Cantabria Region (Northern Spain). Specifically, the canning industry in Cantabria Region produced in 2014 more than 14,000 metric ton of canned anchovies, generating more than 100 million euros. Cantabrian anchovy constitutes a well known gourmet product with important economic and food tourist implications. In order to survive in an increasingly competitive global market, the Cantabrian canned anchovies must be able to design local strategies that contribute to their overall development. According to this, a diversification strategy and introduction in new green markets must be supported by a specific eco-efficiency study (García et al. 2017). Eco-efficiency should deliver competitive goods and services from an economic perspective; however, it should be linked to a progressive reduction in environmental impacts throughout their life cycle (Lorenzo-Toja et al. 2016). Previous studies conducted by Laso et al. (2016a) determined that a hot spot of anchovy canning industry was the generation of high amounts of anchovy wastes (heads, spines, remaining anchovies) which must be managed. The valorization of these residues rather than disposal or incineration introduces in this sector the concept of circular economy. This approach aims to keep the added value in products for as long as possible and eliminate waste (European Commission, 2014). Circular economy has usually been oriented towards materials recycling (Hatayama et al. 2014), increasing now its use to food products. In this sense, this study proposes a circular economy approach to manage the anchovy residues. Anchovy wastes can be valorized into fishmeal, which can be employed for aquaculture. Hence, humans are finally consuming fish species breed with feed from anchovy residues, closing the loop of the original product life cycle. Moreover, the use of anchovy residues from the canning process to produce fishmeal contributes to reduce the overexploitation of the anchovy fishery and to promote a more sustainable use of the marine resources.

Previous works of the authors evaluated the environmental impact of the whole anchovy life cycle (Laso et al. 2016b; 2017a; 2017b) and the different alternatives for the management of anchovy residues (Laso et al. 2016a). However, it is necessary to go further, developing a method to joint computation of environmental and economic indicators in order to attain eco-efficiency benchmarks of anchovy canning sector. According to the ISO 14045 standard, eco-efficiency quantification requires that the environmental performance of a process or product should be directly related to their economic value (ISO 14045, 2012). For instance, the Life Cycle Assessment (LCA) method standardized through the ISO 14040 and 14044 guidelines was used to determinate the environmental impacts linked to the anchovy life cycle (ISO 14040, 2006; ISO 14044, 2006). On the other hand, the Life Cycle Costing (LCC) was employed to quantify the monetary value. LCC is a comprehensive decision-making tool for calculating the total cost, which is generated over the entire life cycle of products or processes (Yang et al. 2017). A methodology to evaluate circular economy by means of a new value-based indicator was proposed by Di Maio et al (2017). These authors suggested measuring both resource efficiency and circular economy in terms of the market value of stressed resources. This methodology defines circularity as the percentage of the value of stressed resources incorporated in a service or product that is returned after its end-of-life. As novelty, our paper introduces linear programming (LP) to combine LCA and LCC methods to reach an eco-efficiency index that attempts to quantify circular economy, beyond the usual theoretical and qualitative descriptions. According to this, the paper introduces a methodological tool to evaluate the environmental and economic value of a product, contributing to simplify decision making process by an objective classification of different scenarios within the canning sector.

Material and methods

The environmental impacts have been estimated using LCA, according to ISO 14040 and 14044 specifications (ISO 14040, 2006; ISO 14044, 2006). The LCC methodology applied in this work is based on the approaches described by Hunkeler et al. (2008) and Swarr et al. (2011) and is congruent with the LCA methodology.

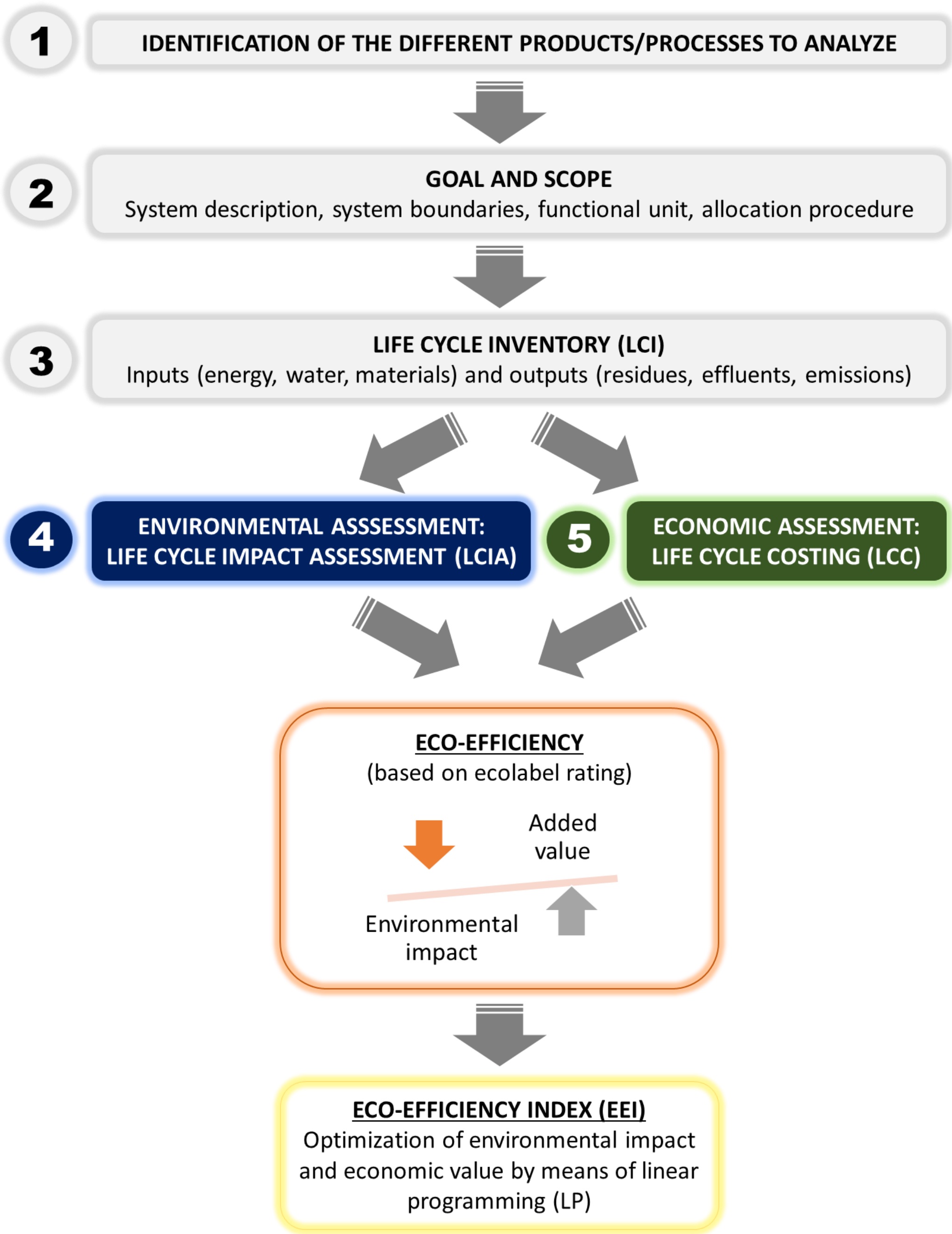

Figure 1. Stages of the eco-efficiency method.

According to Figure 1, the procedure includes the following five main steps:

1. Identification of the different products/processes. This method can be applied to any product or process.
2. Goal and scope. Following the LCA methodology, the goal of the study should be defined, whereas within the scope, a description of the functional unit, system boundaries of the scenarios under study and allocation procedure should be provided

3. Life cycle inventory. In this step is conducted the data collection of the different scenarios under study. The main inputs (energy, water and materials) and outputs (residues, effluents, emissions and products) are referred to the functional unit defined in the previous step.
4. Environmental assessment: life cycle impact assessment (LCIA). In this step, the environmental impact of the different scenarios under study was calculated. The LCI is converted into environmental indicators by means of the emission factors stablished by each LCIA method.
5. Economic assessment: life cycle costing (LCC). The execution of an LCC enables the potential cost drivers and cost savings of a product or service to be identified over its entire life cycle. Therefore, to estimate the total costs of the different scenarios, it is necessary to establish a price for each input and output of LCI.

The proposed methodology combining LCA and LCC results allows important relationships and trade-offs between the economic and environmental performance of the alternative scenarios, helping decision-making.

1.1. Identification of the different products to analyze

This study was conducted for the canning industry of Cantabria Region (Northern Spain). The quality and prestige of canned anchovies are of particular relevance in this Region. Nevertheless, this sector has undergone several economic and environmental problems. On one hand, in recent years, the stock level of the Cantabrian anchovy (Engraulis encrasicolus) has experienced critical situations, whereas the costly distribution to new markets has hindered the growth of the sector. As result, canning plants were forced to import anchovies from other countries. Based on the market demand and characteristics, anchovies may come from Cantabria (*Engraulis encrasicolus*), Argentina (*Engraulis anchoita*), Chile and/or Peru (*Engraulis ringens*). In addition, canning process generates large amounts of anchovy residues, which must be managed in a sustainable way. Therefore, it is necessary to evaluate the eco-efficiency of canning industry of the different scenarios taking into account anchovy importation from Argentina and Chile/Peru and the management of the anchovy residues under a circular economy approach.

1.2. Goal and scope

The main objective of the present study is to propose a method to assess the eco-efficiency of canned anchovy products under a life cycle approach, although this procedure can be used with any other product or process. To conduct this analysis, the functional unit (FU) defined was 1 kg of raw anchovy entering the factory, according to Hospido et al. (2006).

Figure 2 displays the system boundaries and the four different scenarios analyzed. The system under study included the capture of the anchovy, the production of the different ingredients (raw materials), their transport to the canning factory located in Cantabria and the processing and packaging of the anchovies at the canning plant. Therefore, the analysis was performed from cradle to gate.

As mentioned in Section 2.1, depending on the Cantabrian anchovy stock level, anchovies may be imported from other countries, such as Peru/Chile (Scenario 1) and Argentina (Scenario 2). Peruvian and Chilean anchovies are imported ready to be filled with olive oil and packed in Cantabria. That means that anchovies arrive to Cantabria after the pretreatment (beheading and curing) and transformation (scalding, cutting and filleting) steps.

Argentinian anchovies are beheaded, cured (pretreatment stage) and transported to the Cantabrian to canning plant, where takes place the transformation, sauce filling and packing stages. In both scenarios (1 and 2) landfilling was considered as end of life alternative of anchovy residues.

In Scenario 3 both anchovy fishing and canning processes were carried out in Cantabria. This scenario evaluated two waste management alternatives, Scenario 3a in which anchovy residues were disposed in a landfill with biogas recovery and Scenario 3b that considered anchovy residues incineration.

Scenario 4 goes further, introducing circular economy approach with the valorization of the anchovy residues. Heads and spines from the pre-treatment and transformation are sent to a reduction factory to produce fishmeal that will be used in aquaculture. On the other hand, in the canning plant broken and rests of anchovies are reused in the elaboration of anchovy paste. It was considered that fishmeal from anchovy residues was used as feed in bass (*Micropterus salmoides*) aquaculture in the region.

Regarding the management of the anchovy residues, it was considered that the landfill (Scenarios 2 and 3) had biogas recovery and the incinerator energy recovery (Scenario 3), therefore it is denominated waste-to- energy plant. Moreover, the valorization of the anchovy residues (Scenario 4) generated by-products (bass and anchovy paste). Therefore, the anchovy canning process is a multi-output process in which the production of the canned anchovies is the main function of the system, and the by-products from landfilling, incineration and valorization are additional functions. The environmental burdens must be allocated among the different products, that is canned anchovy, energy (from landfill and incineration) and bass and anchovy paste (from anchovy valorization). To handle this problem, the ISO 14040 establishes a specific allocation procedure in which system expansion is the first option. In this case, the electric power mix of Spain in 2015 included in the ELCD-PE GaBi database was selected as the replaced technology in energy production from the landfill and the incineration plant. On the other hand, bass aquaculture where bass was fed by fishmeal from fresh anchovy (including fishing activity) and the production of tuna pâté were selected as the alternative systems that replaces the valorization system of the anchovy residues, taking into account the different fuel use efficiency of the tuna and anchovy fleets (Laso et al, 2017).

As is the case in LCA, multi-functionality is another important issue when carrying out LCC. In LCA, this multi-functionality was handle by system expansion, but in LCC, by-products with market value can simply translate into revenues for the producer. Revenues from by-products may have a great influence on the viability of waste management activities (Escobar et al. 2015). Therefore, Scenario 3 considered in the LCC the incomes from selling the energy from waste to the grid. Similarly, the revenues from the marketable products obtained from the anchovy residues valorization (anchovy paste and bass) in Scenario 4 were also considered, as is explained in Section 2.5.

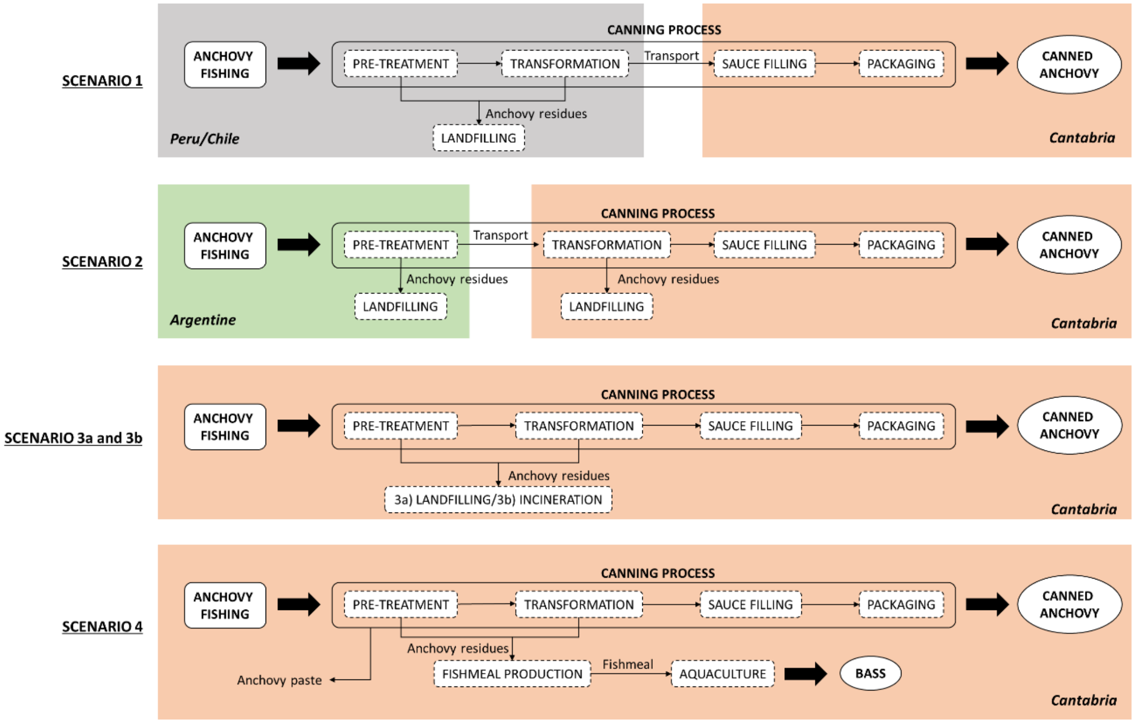

Figure 2. Scenarios under study.

1.3. Life cycle inventory (LCI)

The input and output flows of the different stages of the anchovy life cycle were collected from previous LCA studies. Table 1 shows the mass of fresh anchovy entering in the different scenarios (1 kg of fresh anchovy) and the auction prices of each of the anchovy species. The anchovy fishing by purse seining vessels in Cantabria was taken from Laso et al. 2017a, whereas data from Fréon et al. 2014a were adapted to evaluate the anchovy fishing in Chile/Peru. Due to the lack of data about the anchovy fishing in Argentina, it was considered the same data from Chile/Peru. This assumption was possible because these countries use the same fishing method (purse seining) and a similar size of vessels. Table 2 represents the life cycle inventory of canned anchovy processing which was collected from Laso et al 2016b; 2017b. Tables 3 and 4 depicted data on the production of fishmeal to feed bass from aquiculture. Fishmeal production was taken from Fréon et al. 2017, while aquaculture of bass was obtained from Jerbi et al. 2012 and OPP (2009). On the other hand, landfill with biogas recovery and incineration with energy recovery, were taken from the PE database (PE International, 2014). Secondary data regarding the production of raw materials and transports come from PE database and Ecoinvent® 3.1 (Frischknecht et al. 2007). These databases provide the most robust life cycle inventories on the market with representative data for

Europe conditions.

Cost data have been obtained from literature, market reports and the factory information. In particular, Cantabrian anchovy auction price was taken from the Spanish Ministry of Industry, Tourism and Trade (MINECO, 2017), whereas the other anchovy species (Argentinian and Peruvian/Chilean) data were provided by the factory. Oil prices came from the International Olive Oil Market (IOOM, 2016), Poolred (2017) and Indexmundi (2016), while commodity chemical were obtained from chemical companies. Packaging prices were from LME (2017), Plastics Informat (2017) and LetsRecycle (2016). Waste management data were taken from Tecnoaqua (2016) and the European Topic Centre on Sustainable Consumption and Production (Gentil et al., 2014). Diesel and fuel oil were from Global Petrol Prices (2017) and Electricity costs were sourced from Eurostat (2016). Life cycle costs for anchovy paste and fishmeal production were estimated using the LCI data and costs previously described. Same procedure was followed for bass aquaculture using fishmeal as feed.

Selling price for bass was sourced from the Spanish Aquaculture Business Association (APROMAR, 2016) and anchovy related products were average market data. Regarding fish residues incineration, 85.7% of the electricity generated was assumed to be sold to the grid according to the organic waste incineration model developed by Margallo et al. (2014). It was also considered that the electricity selling price was equal to the purchase cost.

In the Tables 1-4, the economic data are given per unit of measure.

Table 1. Life cycle inventory of the anchovy fishing (auction price).

I/O	Flow	Unit	For the 3 origins	Cantabria (€)	Argentine (€)	Chile/Peru (€/unit)
O	Fresh anchovy	kg	1.00	3.50	2.80	1.75

Table 2. Life cycle inventory of anchovy processing in canning plants.

I/O	Flows	Unit	Cantabria	Argentine	Chile/ Peru	Price (€/unit)
PRE-TREATMENT						
I	Fresh anchovy	kg	1.00	1.00	1.00	Table 1
I	Salt	kg	0.55	0.55	0.55	0.03
I	Brine	m^3	$5.67 \cdot 10^{-4}$	$5.05 \cdot 10^{-4}$	$5.05 \cdot 10^{-4}$	$9.27 \cdot 10^{-3}$
I	Olive oil	kg	0.30	0.18	0.19	3.60
I	Energy	MJ	1.20	1.01	1.00	0.04
I	Water	m^3	$5.21 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	1.10
I	Aluminum	kg	0.04	0.03	0.03	1.67
I	Cardboard box	kg	0.05	0.04	0.04	0.13
I	Corrugated cardboard	kg	0.02	0.02	0.02	0.13
I	Plastic (LDPE)	kg	$1.26 \cdot 10^{-3}$	$6.24 \cdot 10^{-3}$	$6.26 \cdot 10^{-3}$	1.82
I	Natural gas	m^3	$1.50 \cdot 10^{-2}$	$1.30 \cdot 10^{-2}$	$1.30 \cdot 10^{-2}$	$2.34 \cdot 10^{-4}$
O	Canned anchovy	kg	0.31	0.26	0.26	-
O	Wastewater	m^3	$5.21 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	-
O	Anchovy residues (to fishmeal)	kg	0.24	0.24	0.24	0.25
O	Anchovy residues (to anchovy paste)	kg	$3.50 \cdot 10^{-2}$	$1.3 \cdot 10^{-2}$	$1.3 \cdot 10^{-2}$	0.11
O	Discards and losses	kg	0.41	0.48	0.48	0

Table 3. Life cycle inventory of fishmeal production (adapted from Fréon et al. 2017).

I/O	Flows	Unit		Price (€/unit)
I	Anchovy residues (heads and spines)	kg	0.24	0
I	Antioxidants	kg	$2.50 \cdot 10^{-5}$	173
I	Sodium hydroxide	kg	$1.67 \cdot 10^{-4}$	10.50
I	Sodium chloride	kg	$1.45 \cdot 10^{-4}$	3.24
I	Copper wire	kg	$1.00 \cdot 10^{-6}$	$5.40 \cdot 10^{-3}$
I	Electricity	MJ	0.01	0.04
I	Diesel	MJ	0.59	1.34
I	Fishmeal bag	kg	0.13	1.82
O	Fishmeal	kg	0.05	0.25
O	Fish oil	kg	$9.80 \cdot 10^{-3}$	-
O	Suspended solids	kg	$1.88 \cdot 10^{-3}$	0
O	Oil and fat	kg	$1.07 \cdot 10^{-3}$	0
O	BOD_5	kg	$3.72 \cdot 10^{-3}$	0

Table 4. Life cycle inventory of bass aquaculture (adapted from Jerbi et al. 2012; OPP, 2009).

I/O	Flows	Unit		Price (€/unit)
I	Feed (fishmeal)	kg	0.05	0
I	Electricity	MJ	0.20	0.04
I	Sea water	m^3	0.85	0
I	Injected oxygen	kg	0.04	0.13
I	Steal	kg	$2.24 \cdot 10^{-3}$	0.41
O	Bass	kg	0.03	0.46
O	Solid nitrogen	kg	$6.00 \cdot 10^{-4}$	0
O	Dissolved nitrogen	kg	$3.00 \cdot 10^{-3}$	0
O	Solid phosphorus	kg	$4.30 \cdot 10^{-4}$	0
O	Dissolved phosphorus	kg	$1.48 \cdot 10^{-4}$	0

1.4. Environmental assessment - Life cycle impact assessment (LCIA)

The LCIA was conducted with the software Gabi 6.0 (PE International, 2014) and using a mix of impact categories from different assessment methods, according to the recommendations of the Joint Research Centre (JRC) of the European Commission (ILCD, 2011; Hauschild et al. 2013). The environmental indicators included Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and ReCIPE Single Score (SS). GWP, AP and EP are typical LCA impact categories used in many environmental studies of fisheries (Emanuelsson et al. 2008; Hospido and Tyedmers 2005; Ramos et al. 2011; Vázquez-Rowe et al. 2010a; Vázquez-Rowe et al. 2010b; Vázquez-Rowe et al. 2011; Vázquez-Rowe et al. 2012; Ziegler et al. 2003). ReCIPE provides a harmonized implementation of cause-effect pathways for the calculation of both midpoint and endpoint characterization factors (Huijbregts et al. 2017). ISO standards remarks that the use of aggregated single scores could reach different final results. This is due to their normalization and weighting procedure is based on value judgments and they do not have a scientific base. However, the introduction of a ReCIPE endpoint SS was considered in this study because is an aggregated single score, which encompass 16 different impact categories (Lorenzo-Toja et al. 2016), and facilitates the decision-making process. The IPCC 2013 assessment method, 100-year time horizon, was used to compute the greenhouse emissions (IPCC, 2013), and the CML-IA baseline method (Guinée et al. 2002) was selected to calculate AP and EP.

1.5. Economic assessment - Life cycle costing (LCC)

LCC helps to identify those steps that constitute an opportunity to reduce costs, while helping decision-makers to choose a cost-effective project alternative (Escobar el al. 2015). It includes manufacturing cost, maintenance and replacement cost, energy and residual values.

The LCC of the anchovy canning industry was assessed from cradle to gate ($LCC_{cradle\ to\ gate}$) according to Eq. (1).

$$LCC_{cradle\ to\ gate} = C_{RM} + C_{PP} + C_M + C_P + C_{WT} \quad (1)$$

Where C_{RM} are the costs of raw materials (including fishery), C_{PP} are the costs of pre-processing of raw materials, C_M are the costs of anchovy processing and manufacturing, C_P are the costs of primary and secondary packaging and C_{WT} are the management costs of waste treatment.

Furthermore, the value added (VA) is also estimated in this work according to Rivera and Azapagic (2016), which is defined as the difference between total incomes and costs of bought-in materials and services. It describes somehow the profit margin of each product for the manufacturers, providing an insight into the value to manufacturers and to society at large. It was estimated as follows:

$$VA = WP - LCC_{cradle\ to\ gate} \quad (2)$$

Where WP is the wholesale price or price charge to trade buyers for the canned anchovies and sub-products of the system (anchovy paste, bass, and electricity) and $LCC_{cradle\ to\ gate}$ are the life cycle costs from cradle to gate. Owing to the lack of data, retail instead of wholesale prices are used.

The operational costs, incomes and added value of each scenario were calculated through the computation of the detailed cost inventories, following the methodological approach presented in Section 2.5.

2. Results and discussion

2.1. Eco-efficiency of canned anchovy products

Table 5 shows the contribution of cost stages such as the production of canned anchovies, anchovy paste, fishmeal and bass. The analysis of the cost of the five scenarios under study showed that the scenarios in which the anchovy fishing was carried out in Cantabria presented the highest costs. This was due to the fact that the purse seining fleet in Cantabria used higher amount of diesel than the purse seining fleet in Peru (340 and 15.6 g diesel/FU, respectively) (Laso et al. 2017a). This fact resulted in an increase in the price of the fresh anchovy in the auction at port (see Table 1). Moreover, Scenario 4 presented the highest total cost owing to the sum of the costs of the anchovy residues valorization into anchovy paste and fishmeal to bass aquaculture. Although almost 100% of the total costs belonged to the canned anchovy production.

Despite the fact that the scenarios in which the anchovy was captured in Cantabria presented greater costs of production, it should be taken into account that high quality of the Cantabrian canned anchovies, considered as a “gourmet product”, resulted in higher incomes in these scenarios (3a, 3b and 4). In the case of Cantabrian canned anchovy, it was obtained 23.3€/FU of incomes versus 9.14€/FU for Peru/Chile (Scenario 1) and 3.08€/FU for Argentine (Scenario 2). In addition to canned anchovy incomes, it was also considered the incomes from selling the recovered electricity in the landfill and incineration to the grid (Scenario 3a and 3b) and the incomes from anchovy paste and bass. Therefore, the production of canned anchovy from Cantabria and the valorization of the anchovy residues into marketable products (Scenario 4) presented the highest total incomes (24.77€/FU) versus the Scenario 1 which presented the lowest incomes (9.14€/FU).

Finally, making a balance between the total costs of production and the total incomes, the added value for each scenario was obtained. Scenario 4 had the highest added value (20.18€/FU) because, although it presented the greatest costs of production, it also had the highest total incomes. The valorization of the anchovy residues increased the added value of the Scenario 4, but it is necessary to calculate the environmental impacts linked to the different scenarios under study to determine their eco-efficiency.

Table 5. Economic balance of each scenario under study.

	Scenario 1	**Scenario 2**	**Scenario 3a**	**Scenario 3b**	**Scenario 4**
Costs (€)					
Canned anchovy production	1.84	3.08	4.56	4.56	4.55
Anchovy paste production	-	-	-	-	$3.77 \cdot 10^{-3}$

Fishmeal production	-	-	-	-	0.02
Bass production	-	-	-	-	0.01
Total costs	**1.84**	**3.08**	**4.56**	**4.56**	**4.59**
Incomes (€)					
Canned anchovy	9.14	12.40	23.30	23.30	23.30
Anchovy paste	-	-	-	-	1.28
Bass	-	-	-	-	0.19
Electricity to the grid	-	-	$1.18{\cdot}10^{-3}$	$1.60{\cdot}10^{-3}$	-
Total incomes	**9.14**	**12.4**	**23.30**	**23.30**	**24.77**
Added value (€)	**7.30**	**9.32**	**18.74**	**18.74**	**20.18**

The different environmental impacts and the added value of each of the scenarios under study are represented in Figures 3. Based on the combination between each of the four environmental indicators and the added value, the different scenarios were classified into three eco-efficient categories: A, B and C. An "A" rating represents the most eco-efficient scenario, whereas "C" rating represents those with the lowest eco-efficiency. The reference value used to fix the segregation between these categories was the quartiles obtained from the totality of the sample. In this way, in order to attain the highest rating (i.e., A) the respective environmental and economic indicators should be lower than the Q1. Similarly, to obtain a "B" rating, the indicators must be situated between Q1 and Q3. Finally, an anchovy product achieves a "C" rating when the indicators are higher than the threshold value for Q3. This methodology based on the combination of environmental and economic impacts has been used by Lorenzo-Toja et al (2016) to define the eco-efficiency of a set of 22 wastewater treatment plant in Spain. However, as economic indicator, Lorenzo-Toja and colleagues used costs of treating 1 m^3 of water while this study employed the added value, taking into account the costs as well as the incomes.

GWP is one of the most well-known and commonly-used environmental indicators. The energy intensity of the production of some raw materials makes important including this impact category in the assessment. The energy consumption, mainly due to the production of the packaging has been reported as one of the main environmental hotspots for the GWP impact category within canning industry (Almeida et al. 2015; Hospido et al. 2006; Laso et al. 2016). Results for GWP ranged from 0.88 (Scenario 1) to 2.68 kg CO_2 eq/FU (Scenario 3a). Figure 3 presents the GWP impacts (kg CO2 eq/FU) and the added value (€/FU) of all the scenarios under study. The Scenario 4 presented excellent results for both GWP and the economic indicator, obtaining the “A” qualification. Interestingly, the Scenario 4 was the scenario which applied the circular economy as an economic and environmental strategy to valorize the anchovy residues and convert them into marketable products. The rest of scenarios obtained the intermediate “B” qualification because some of them presented low GWP but low added value (Scenario 1 and 2) or vice versa, high added value but high GWP.

The trend in the other impact categories was similar to GWP. The values of AP ranged from 0.005 (Scenario 1) to 0.03 kg SO_2 eq (Scenario 3a and 3b), the values of EP varied between 0.001 (Scenario 1) and 0.006 kg SO_4^{-3} eq/FU (Scenario 3a). In this case, both Scenario 1 and 4 obtained the “A” qualification. Scenario 1 had AP and EP values very low, but also, this scenario presented the lowest added value because the canned anchovy product elaborated with Peruvian/Chilean anchovies was the cheapest of the different products analyzed.

The final environmental indicator included for the benchmarking of the anchovy products was the single ReCIPE SS endpoint. This indicator facilitates the communication of the results to the stakeholders. However, the results should be interpreted with caution, taking into account the higher uncertainty within this environmental method. The values for this indicator range from 0.08 (Scenario 1) to 0.28 Pt (Scenario 3a). In this case, only the Scenario 4 obtained the “A” qualification, whereas the rest of the scenarios had “B” qualification.

Finally, with the environmental indicators considered, there was no scenario that presented a “C” qualification.

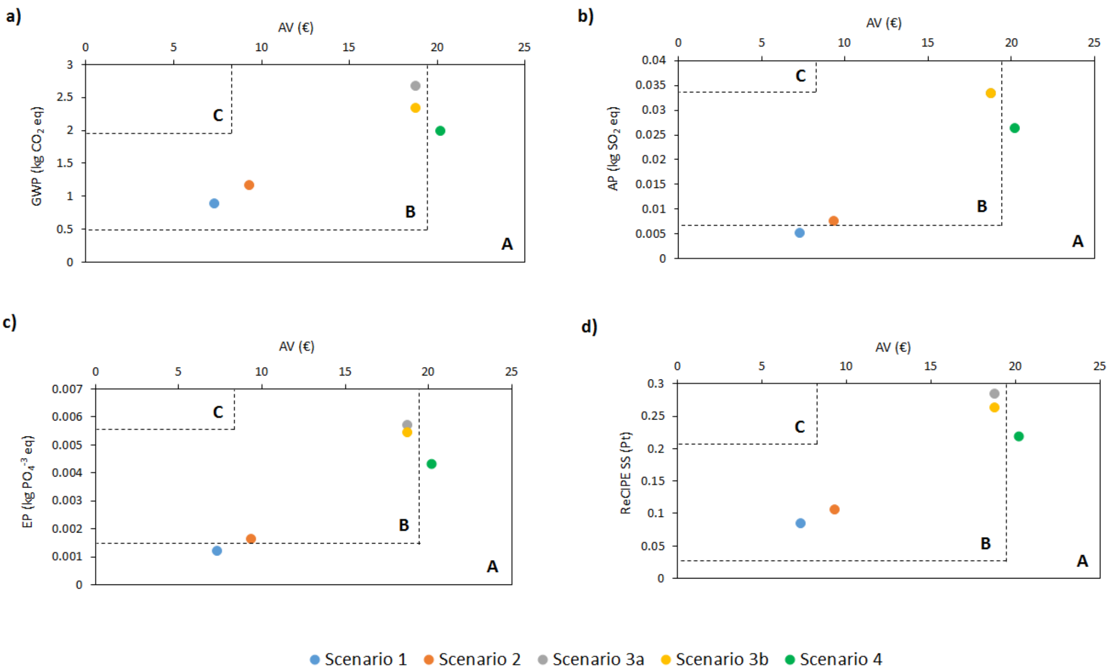

Figure 3. Environmental impacts and added value (€) of each scenario under study. a) Global Warming Potential; b) Acidification Potential; c) Eutrophication Potential; d) ReCIPE Single Score.

The methodology described, based on performance quartiles, permitted the extraction of a rating letter for each of the environmental and economic indicators computed. The rating letters could be ordered based on the importance given to the selected environmental indicators in previous literature studies: i) GWP, ii) AP, iii) EP and iv) ReCIPE SS endpoint. Therefore, the rating method scales from "AAAA" to "CCCC". Based on this scale, Scenario 4 presented a rating of "AAAA", which it is represented in Figure 4 by "A". This scenario had the highest eco-efficiency. None of the assessed scenarios presented a rating of "CCCC". Scenario2, 3a and 3b reached an intermediate rating "BBBB" represented in Figure 4 by "B". Finally, Scenario 1 had a rating of "BAAB" represented by "B^{+}".

This method is highly dependent on the characteristics of the units contained in the sample because they will affect the quartiles and, ultimately, this fact will predetermine the placement of the scenarios in the different rating groups. However, it seems to be robust enough to guide priority measures to avoid food loses and promote sustainable policy that improving the eco-efficiency of food products.

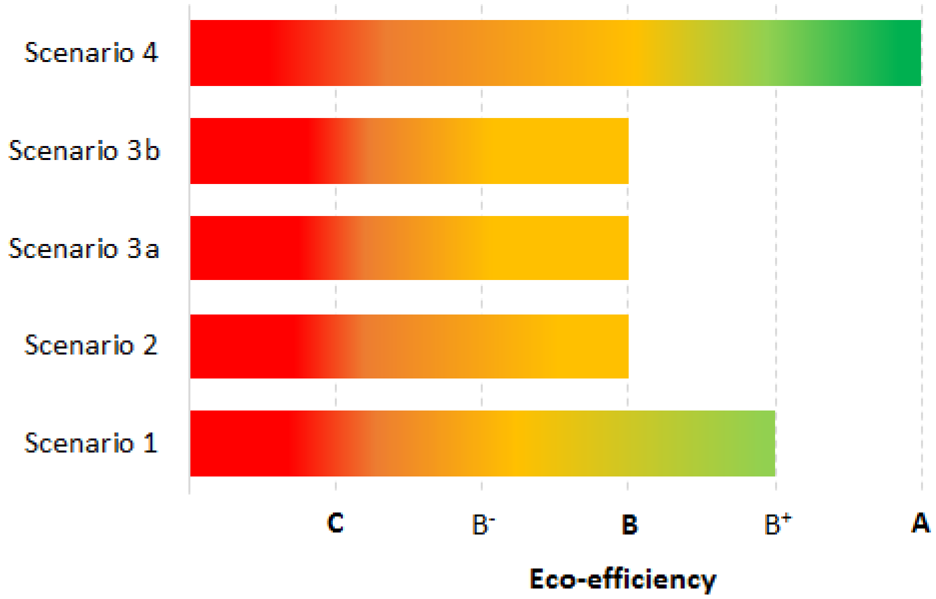

Figure 4. Eco-efficiency of the scenarios under study

3.2. *Aggregate eco-efficiency index (EEI)*

In some scenarios, the decision-making could be confusing because we have to choose between giving more weight to the environment or economic aspect. Therefore, it is necessary to introduce a methodological approach which facilitates the decision-making process. In this work, we propose a composite eco-efficiency index. This approach is an attempt to enable the translation into economic terms of the environmental damage caused when a given alternative is chosen.

Given a set of scenarios under study and the eco-efficiency results associated to them, an aggregated eco-efficiency index (EEI) was developed. EEI is obtained by minimizing the weighted sum of economic (I1) and environmental (I2) impacts as follows:

$$EEI = w_1 I_1 - w_2 I_2 \qquad (3)$$

Where I_1 is the *AV* and I_2 is the ReCIPE SS. Since I_2 represents the environmental damage in points ("Pt"), its sign is reversed with regard to I_1. Hence, the larger the EEI score is, the more eco-efficient a scenario results. w_1 is the weighting factor of I_1, which is set to 1 so that EEI can be expressed in monetary units, reflecting thus the significant influence the market price. w_2 is the *environmental damage penalty (EDP)* and reflects the environmental damage in economic terms (€/Pt) that stake-holders are willing to assumed at the expense of producing more valuable products. Its meaning is similar to the CO_2 emission allowances stated by the EU Emissions Trading System (EU ETS, 2003). However, our EDP describes the economic penalty that would be applied in the hypothetical situation that not only CO_2 is considered as cornerstone of environmental policies, but also the environmental damage to human health, ecosystems and resource availability.

The aim of this analysis is to identify, for each scenario s, the lower and upper limits of the weighting factors [$\underline{w_{s,t}}, \overline{w_{s,t}}$] attached to each impact category t such that if the weight attached to the category falls outside the interval, then the solution will be suboptimal (Cortés-Borda et al. 2013). The intervals were determined solving the LP equations:

Model 1: minimizing w_s Model 2: maximizing w_s

$$\underline{w_{s,t}} = min\ w_s \qquad (4) \qquad\qquad \overline{w_{s,t}} = max\ w_s \qquad (5)$$

$$\sum_s w_s \cdot I_{s,t} \geq \sum_s w_s \cdot I_{s,t'} \quad \forall t \neq t' \qquad (6)$$

$$w_s^{LO} \leq w_s \leq w_s^{UP} \qquad (7)$$

Table 6. Results of the minimum and maximum weighting values for w_2

Scenario	w_2 min (€/Pt)	w_2 max (€/Pt)	EEI (€)
1	77.69	86.90	0.77-0.00
2	55.41	77.69	3.23-0.77
3a	0.00	55.41	18.74-3.23
4	0.00	91.73	20.18-0.00

As a first step, only landfill scenarios (1, 2 and 3a) were considered in order to assess the influence of the anchovy origin. As Table 6 suggests, Cantabrian anchovies would be the preferred option for hypothetical EDPs until 55.41€, obtaining a maximum EEI of 18.74€. For larger EDP values until 77.69 €/Pt, Argentine anchovies would be the more eco-efficient scenario, achieving a maximum EEI of 3.23 €. Conversely, higher penalties than 86.9€ would involve negative scores of EEI and thus none of the scenarios would be desirable. It can also be highlighted that the Cantabrian scenario is the more adaptable, since it presents the wider range of admissible EDP values.

Secondly, the Cantabrian valorisation scenario was compared to the rest of scenarios in order to assess the influence of applying circular economy principles. Scenario 3b was omitted from the analysis since it presents worse environmental and economic results than scenario 4. As can be observed, this scenario is more versatile since its admissible EDP range is extended to 0-91.73€/Pt. As previously suggested, higher penalties of 91.73€/Pt are not possible for any scenario, since they would not be profitable. Consequently, Cantabrian valorisation scenario results the more eco-efficient, demonstrating the environmental and economic improvements of applying circular economy.

Consumer may be willing to pay more for a specific product at the expense of assuming a higher environmental impact. However, it is difficult to extrapolate these results to the consumer perspective, since the EDP could be transferred to the end user, increasing the apparent value-added (Bushnell et al., 2013).

LCA systems are typically simplified as linear steady state models of physical flows, where the environmental impacts are directly proportional to the functional unit and there are no synergistic or antagonistic effects (Azapagic, 1999). Same consideration is extended to LCC approach. However, this entails a drastic simplification of the complex reality. If environmental and economic aspects are interdependent or even environmental impacts among them, non-linear programming would be required to account for the more complex, non-linear relations in the real system.

3. Conclusions

One of the main challenges of moving towards sustainable production and consumption is to find out which options are the most sustainable in both environmental and economic terms. Balancing both variables simultaneously is necessary to guarantee the competitive development of products and services.

Our proposal combines LCA and LCC to propose a two-step eco-efficiency methodology assessment for the anchovy canning sector in Cantabria. This methodology is based on the environmental impacts and the added value of the different canned anchovy products. Therefore, in addition to the production costs, it is important to consider the incomes from the market value of the products obtained, such as canned anchovies as well as anchovy paste and bass.

A first approach is addressed by developing an eco-label rating system to classify food products in a clear manner to stakeholders. Secondly, linear programming tools are used to define a composite eco-efficiency index integrated by both environmental and economic indicators. This methodology enables the translation into economic terms of the environmental damage caused by the manufacture of a specific product.

Results demonstrate that the introduction of circular economy principles in the management of the anchovy residues improve the eco-efficiency of the anchovy canning industry. This approach can be applied to other regions and industrial sectors, helping make more deliberate, thoughtful decision, and increasing the chances to choose the most satisfying alternative possible.

Acknowledgements

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Table 1. Life cycle inventory of the anchovy fishing (auction price).

I/O	Flow	Unit	For the 3 origins	Cantabria (€)	Argentine (€)	Chile/Peru (€/unit)
O	Fresh anchovy	kg	1.00	3.50	2.80	1.75

Table 2. Life cycle inventory of anchovy processing

Table 2. Life cycle inventory of anchovy processing in canning plants.

I/O	Flows	Unit	Cantabria	Argentine	Chile/ Peru	Price (€/unit)
PRE-TREATMENT						
I	Fresh anchovy	kg	1.00	1.00	1.00	Table 1
I	Salt	kg	0.55	0.55	0.55	0.03
I	Brine	m^3	$5.67 \cdot 10^{-4}$	$5.05 \cdot 10^{-4}$	$5.05 \cdot 10^{-4}$	$9.27 \cdot 10^{-3}$
I	Olive oil	kg	0.30	0.18	0.19	3.60
I	Energy	MJ	1.20	1.01	1.00	0.04
I	Water	m^3	$5.21 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	1.10
I	Aluminum	kg	0.04	0.03	0.03	1.67
I	Cardboard box	kg	0.05	0.04	0.04	0.13
I	Corrugated cardboard	kg	0.02	0.02	0.02	0.13
I	Plastic (LDPE)	kg	$1.26 \cdot 10^{-3}$	$6.24 \cdot 10^{-3}$	$6.26 \cdot 10^{-3}$	1.82
I	Natural gas	m^3	$1.50 \cdot 10^{-2}$	$1.30 \cdot 10^{-2}$	$1.30 \cdot 10^{-2}$	$2.34 \cdot 10^{-4}$
O	Canned anchovy	kg	0.31	0.26	0.26	-
O	Wastewater	m^3	$5.21 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	$4.42 \cdot 10^{-3}$	-
O	Anchovy residues (to fishmeal)	kg	0.24	0.24	0.24	0.25
O	Anchovy residues (to anchovy paste)	kg	$3.50 \cdot 10^{-2}$	$1.3 \cdot 10^{-2}$	$1.3 \cdot 10^{-2}$	0.11
O	Discards and losses	kg	0.41	0.48	0.48	0

Table 3. Life cycle inventory of fishmeal production

Table 3. Life cycle inventory of fishmeal production (adapted from Fréon et al. 2017).

I/O	Flows	Unit		Price (€/unit)
I	Anchovy residues (heads and spines)	kg	0.24	0
I	Antioxidants	kg	$2.50 \cdot 10^{-5}$	173
I	Sodium hydroxide	kg	$1.67 \cdot 10^{-4}$	10.50
I	Sodium chloride	kg	$1.45 \cdot 10^{-4}$	3.24
I	Copper wire	kg	$1.00 \cdot 10^{-6}$	$5.40 \cdot 10^{-3}$
I	Electricity	MJ	0.01	0.04
I	Diesel	MJ	0.59	1.34
I	Fishmeal bag	kg	0.13	1.82
O	Fishmeal	kg	0.05	0.25
O	Fish oil	kg	$9.80 \cdot 10^{-3}$	-
O	Suspended solids	kg	$1.88 \cdot 10^{-3}$	0
O	Oil and fat	kg	$1.07 \cdot 10^{-3}$	0
O	BOD_5	kg	$3.72 \cdot 10^{-3}$	0

Table 4. Life cycle inventory of bass aquaculture (adapted from Jerbi et al. 2012; OPP, 2009).

I/O	Flows	Unit		Price (€/unit)
I	Feed (fishmeal)	kg	0.05	0
I	Electricity	MJ	0.20	0.04
I	Sea water	m^3	0.85	0
I	Injected oxygen	kg	0.04	0.13
I	Steal	kg	$2.24{\cdot}10^{-3}$	0.41
O	Bass	kg	0.03	0.46
O	Solid nitrogen	kg	$6.00{\cdot}10^{-4}$	0
O	Dissolved nitrogen	kg	$3.00{\cdot}10^{-3}$	0
O	Solid phosphorus	kg	$4.30{\cdot}10^{-4}$	0
O	Dissolved phosphorus	kg	$1.48{\cdot}10^{-4}$	0

Table 5. Economic balance of each scenario under study.

Table 5. Economic balance of each scenario under study.

	Scenario 1	**Scenario 2**	**Scenario 3a**	**Scenario 3b**	**Scenario 4**
Costs (€)					
Canned anchovy production	1.84	3.08	4.56	4.56	4.55
Anchovy paste production	-	-	-	-	$3.77 \cdot 10^{-3}$
Fishmeal production	-	-	-	-	0.02
Bass production	-	-	-	-	0.01
Total costs	**1.84**	**3.08**	**4.56**	**4.56**	**4.59**
Incomes (€)					
Canned anchovy	9.14	12.40	23.30	23.30	23.30
Anchovy paste	-	-	-	-	1.28
Bass	-	-	-	-	0.19
Electricity to the grid	-	-	$1.18 \cdot 10^{-3}$	$1.60 \cdot 10^{-3}$	-
Total incomes	**9.14**	**12.4**	**23.30**	**23.30**	**24.77**
Added value (€)	**7.30**	**9.32**	**18.74**	**18.74**	**20.18**

Table 6. Results of the minimum and maximum weighting values

Table 6. Results of the minimum and maximum weighting values for w_2

Scenario	w_2 min (€/Pt)	w_2 max (€/Pt)	EEI (€)
1	77.69	86.90	0.77-0.00
2	55.41	77.69	3.23-0.77
3a	0.00	55.41	18.74-3.23
4	0.00	91.73	20.18-0.00

Figure 1. Stages of the eco-efficiency method.
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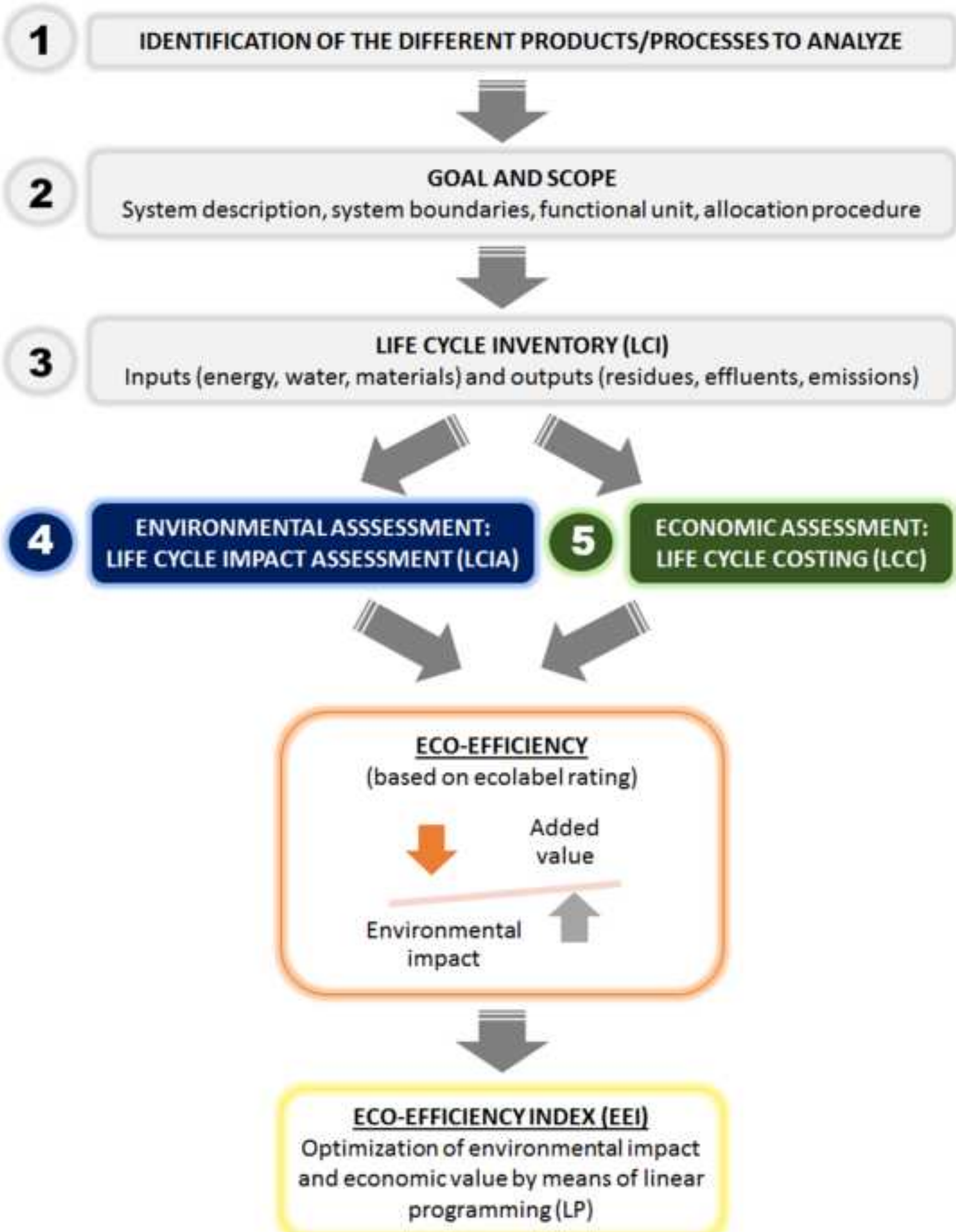

Graphical Abstract

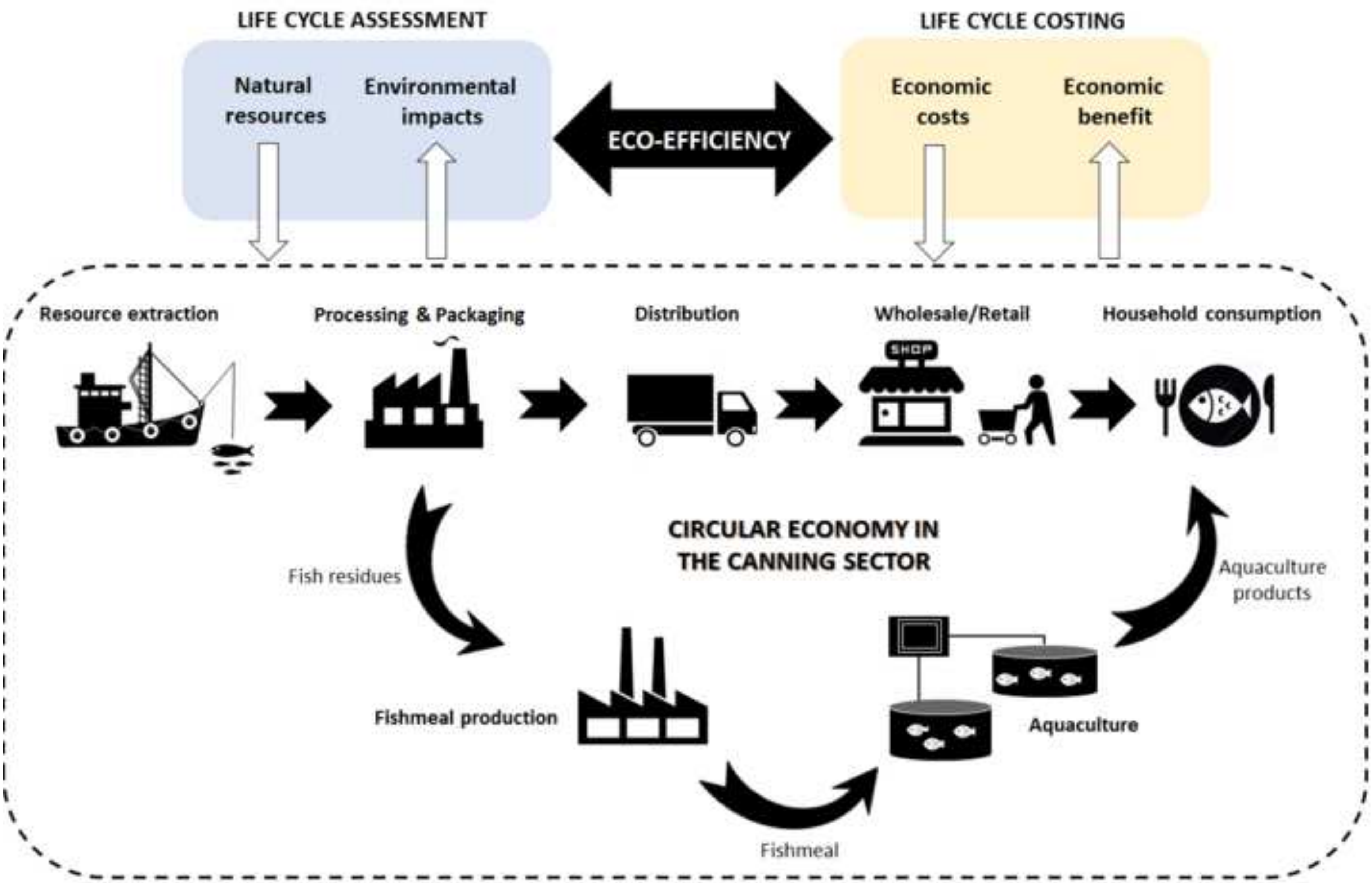

Figure 2. Scenarios under study.
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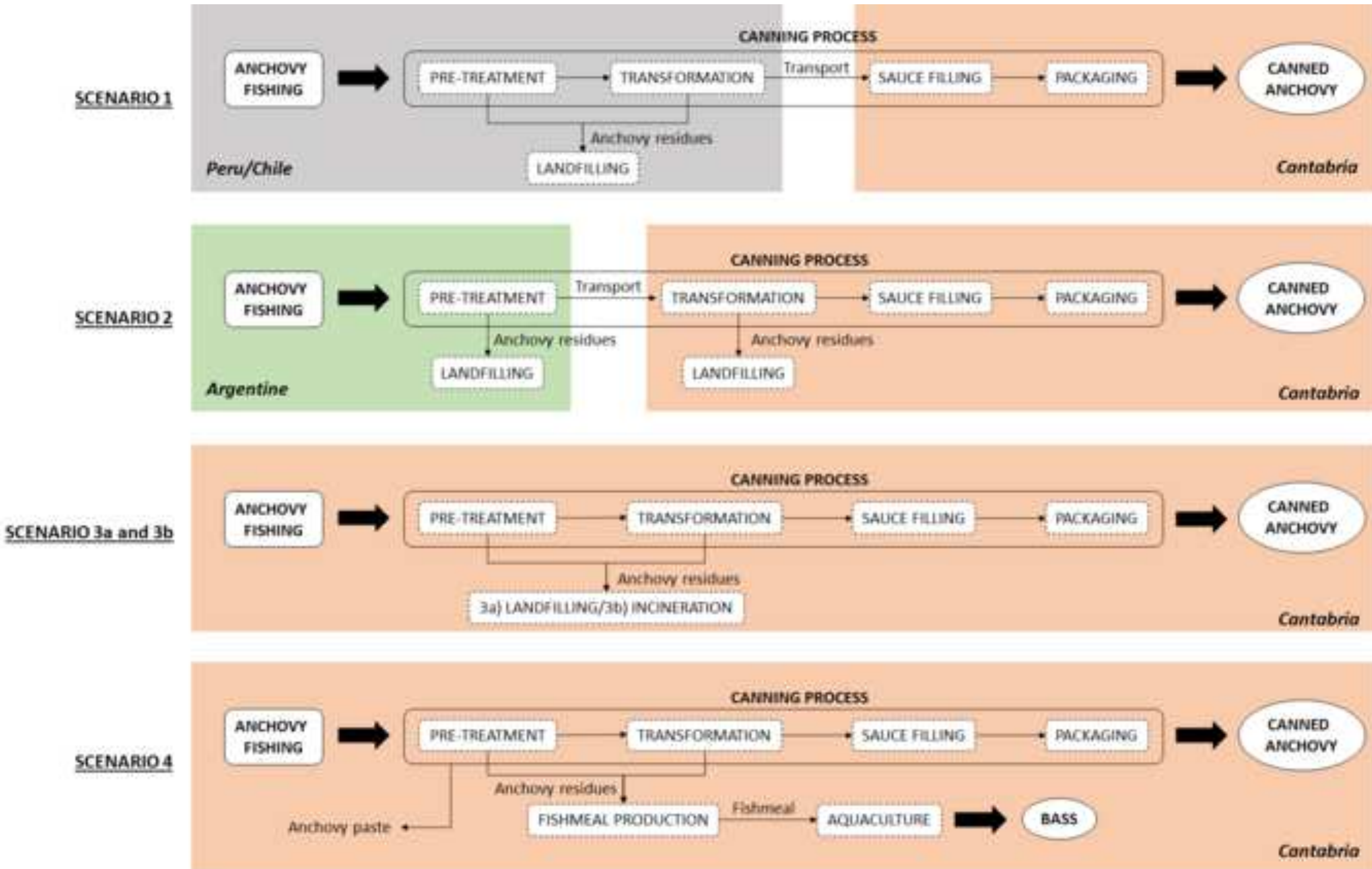

Figure 3. Environmental impacts and added value (?)

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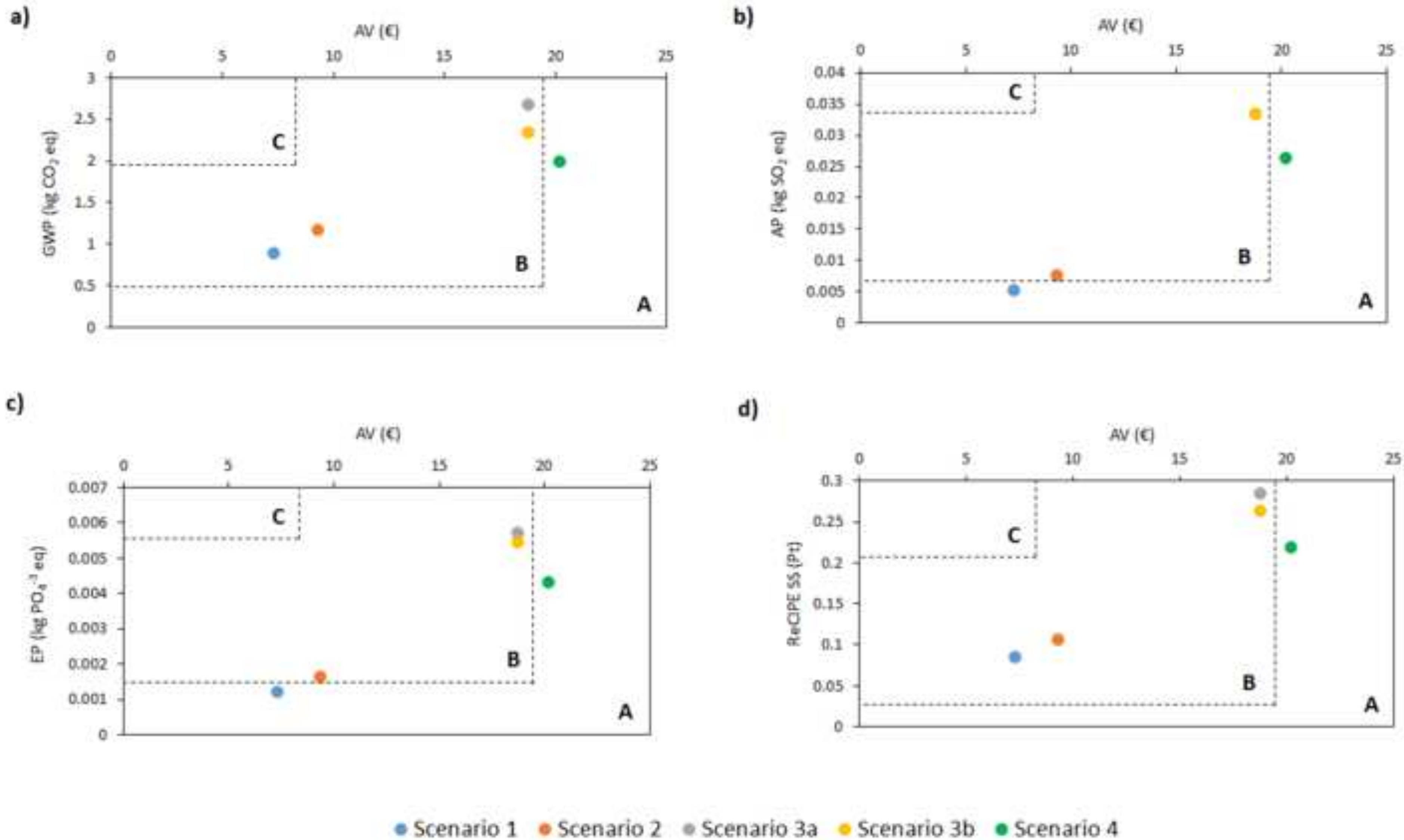

Figure 4. Eco-efficiency
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