

Environmental sustainability pathways based on a single raw material: European pilchard (*Sardina pilchardus*) in NW Spain

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ABSTRACT

European pilchard (*Sardina pilchardus*) is a commonly purchased species in Portugal and Spain, since it constitutes a cheap and healthy source of protein. Therefore, numerous final products are commercialized based on this same raw product. The current study presents a cross-product environmental analysis using Life Cycle Assessment (LCA) for three different final consumer-purchased products based on European pilchard landings in Galicia (NW Spain): canned pilchards, fresh pilchards and European hake caught in the Northern Stock using pilchard bait. Furthermore, the entire life cycle of the products were considered, including a series of different cooking methods for each final product. The midpoint and endpoint results obtained showed important differences in the final environmental impacts between the products, with the different cooking methods also appearing to be a crucial source of uncertainty. The results are analyzed regarding relevant limitations, uncertainties and consumer and policy implications through the use of Mixing Triangles.

Keywords: canning industry, consumption patterns, LCA, Mixing Triangle, seafood

1. Introduction

Iberian countries (i.e., Portugal and Spain) are among the few countries in the world in which protein supply for human consumption associated with the intake of seafood products represents over 20% of the daily protein intake of animal origin (FAO 2012). More specifically, European pilchard (*Sardina pilchardus*) constitutes an attractive seafood product in Spanish and Portuguese households. For instance, the annual per capita consumption of pilchard in Spain is currently around 2.1 kg, only behind tuna and hake products in terms of seafood products (Martín-Cerdeño 2010). Pilchards are usually consumed fresh in the summer months (June to early October) due to their higher levels of fat in this period, improving their taste and aroma (Zlatanov and Laskaridis 2007). During the rest of the year, however, most of the landed pilchard is used mainly for the canning industry or as bait in demersal fisheries. In 2009 a total of nearly 30,000 metric tons of pilchards were canned in Spanish territory, of which approximately 80% was canned in Galicia, a region in NW Spain known for its seafood industry (ANFACO 2011).

Independently of the current overexploitation of the European pilchard stock off the coast of Portugal and NW Spain or the natural fluctuations that this species presents from one year to another, the environmental impacts linked to the operation of the fishing fleet that captures pilchard has historically been ignored. However, the landing, processing and consumption of seafood products has shown to be a relevant source of greenhouse gas (GHG) emissions, due to the intensive energy use in the fishing and canning sectors (Hospido et al. 2006; Vázquez-Rowe et al. 2013). Therefore, an increasingly used methodology to monitor in an integrated manner a range of environmental impacts linked to anthropogenic activities, including fishing, is Life Cycle Assessment – LCA (ISO 2006a). In fact, this method has been used in several recent publications to understand the main environmental dimensions that are affected by fishing activities and their derived supply chains (Vázquez-Rowe et al. 2012).

The main aim of the current study was to understand the environmental impacts using an LCA perspective associated with the entire life-cycle of a selection of three seafood products available for Spanish consumers in supermarkets and other retailing stores derived from the landing of European pilchard. The latter raw material was monitored based on landings performed by Galician purse seiners. However, beyond these particular landings, a cross-product analysis was performed based on an equal amount of protein supply at the plate of the consumer, with the aim of analyzing the variable environmental impacts linked to different processing and/or consumption routes for one single raw product.

The described goals intend to provide support for decision-making at a company level throughout the supply chain, as well as a starting point for the evaluation of integrated policies for the reduction of environmental impacts

in the food sector. Finally, the results will also guide consumers in terms of responsible consumption of seafood products (González et al. 2011).

2. Methods

2.1. Goal and scope definition

The main function of the production system is that of nourishing human communities with a specific amount of protein content (an essential part of human diets) embedded in seafood final products (Pimentel and Pimentel 2003). However, in this specific study a comparison is provided between three different final products at the retailing center for the consumers to purchase, but deriving from one single raw product: European pilchard. Hence, the functional unit (FU) selected was fixed as the amount of protein available (17.26 g) in *Scenario A*, that is, a can of pilchards in olive oil (85.0 g) produced by a Galician canning factory. For the alternative scenarios, the same amount of protein available for the consumer was considered. Therefore, in *Scenario B* a total of 137 g of fresh round pilchard were assumed ready for intake. Similarly, in *Scenario C* the consumers' final intake is 183 g of European hake landed by Galician long liners. However, in the latter scenario it should be noted that this hake is captured using pilchard as bait (75.2 g per FU), which justifies its comparability with the previous scenarios.

2.2. System description

Figure 1 presents a schematic representation of the different subsystems included in the life-cycle of each scenario. Subsystem I comprises the fishing activities to capture and land pilchard and, therefore, is common to all scenarios together with Subsystem II, which includes the auction and port activities. In contrast, Subsystem III only applies to Scenarios *A* and *C*, since *Scenario B* does not include a processing stage (the pilchard is consumed fresh). For the former, Subsystem III comprises the entire processing of the canned pilchard, including the reception and storage of the raw pilchard, cutting and canning of the cleaned pilchard, cooking and the addition of more ingredients (i.e. olive oil and salt), sterilization, packaging and, finally, the distribution of the processed product to the regional distribution center. For *Scenario C*, however, this subsystem is associated with the processing, freezing and distribution of pilchard in the form of bait to supply the Galician long liners, as well as the fishing stage, auction and port activities for the hake landings. Subsystem IV comprises the wholesaling and retailing of the different products, which are thereafter consumed in Galician households (Subsystem V). Moreover, Subsystem V also includes the end-of-life (EOL) activities of the different materials used throughout the supply chain that are disposed of by the consumer (e.g., tins, packaging, organic residues...). Finally, Subsystem VI deals with the human excretion phase based on the assumptions available in Muñoz et al. (2008).

2.3. Data acquisition

Data for the European pilchard fishery were retrieved from a previous study developed by Vázquez-Rowe et al. (2010) that analyzed the Galician purse seining fleet from an LCA approach. Landing and auction activities were inventoried based on data disclosed by the port of Vigo (Autoridad Portuaria de Vigo, personal communication, September 2010). For the processing stage, data for the canning factory were obtained from a canning factory located in *A Coruña* province. This factory destines 95% of its production efforts to deliver canned pilchard. For the baiting data, however, data were delivered by a baiting SME located in *Lugo* province. In addition, European hake landings were obtained from a study undergone by Vázquez-Rowe et al. (2011) that analyzed hake landings by Spanish vessels in the North Atlantic. Finally, the remaining inventory data were retrieved from a wide range of bibliographical sources, including the ecoinvent® database, from which background data for most inventory items were modelled (Frischknecht et al. 2007).

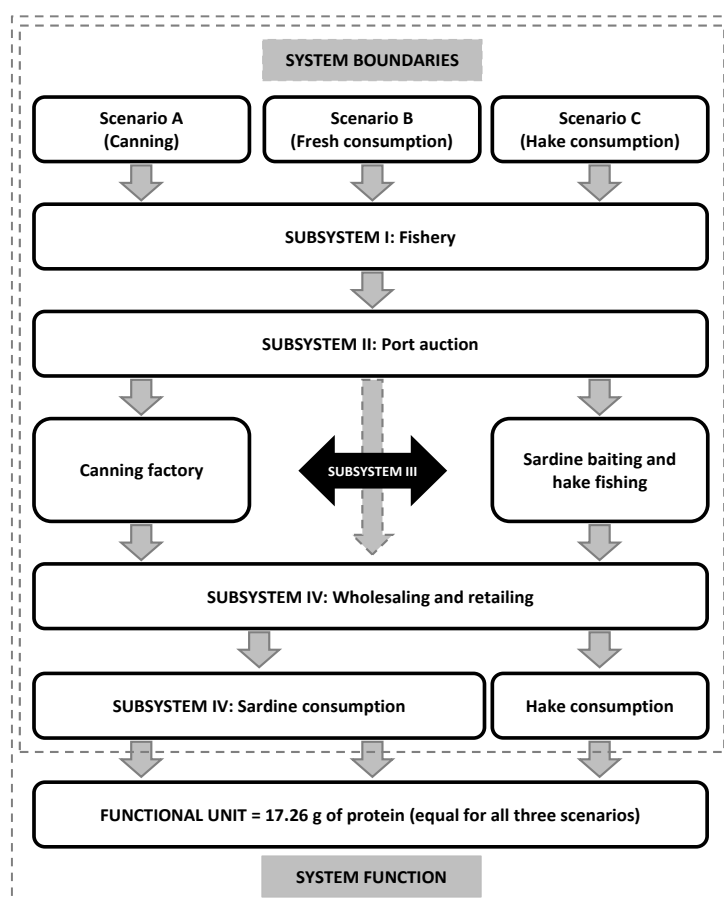


Figure 1. Schematic representation of the analyzed production systems.

2.4. Life Cycle Inventory

The Life Cycle Inventory (LCI) consists of the organization and structuring of the data collected to perform the LCA (ISO 2006b). Table 1 presents a summarized LCI for the three subsystems.

2.5. Allocation and other assumptions

Two different allocation approaches were considered throughout the supply chains analyzed. On the one hand, allocation was identified as been necessary in Subsystem I, since pilchard is captured in a multispecies fishery together with Atlantic mackerel or horse mackerel (Vázquez-Rowe et al. 2010). As recommended by ISO 14044 and the PAS 2050 appendix for seafood products, mass allocation was selected with the aim of accounting for the physical relationship between co-products (ISO 2006b; BSI 2012). On the other hand, in *Scenario A* an important intermediary residue is generated in the canning factory: the portion of the life weight of pilchards that is not used in the cans (141 g per FU). For this particular co-product scenario, three different allocation approaches were used in the three alternative situations considered for *Scenario A*: i) economic allocation based on economic revenues in the canning plant; ii) economic allocation considering economic savings in the factory; iii) energy allocation, which takes into consideration the final amount of protein that the residues provide to humans diets when used for reduction and aquaculture feeding.

Table 1. Summarized Life Cycle Inventory (LCI) for the production systems analyzed. Data referred to the fixed functional unit.

	Unit	Scenario A		Scenario B		Scenario C		
		Economic revenue allocation	Economic savings allocation	Energy allocation	Fried pilchards	Grilled pilchards	Fried hake	Boiled hake
INPUTS								
SUBSYSTEM I								
Diesel	g	39.89	33.91	29.14	24.13	24.13	13.24	13.24
Ice production	g	72.76	61.85	53.14	44.01	44.01	24.14	24.14
Steel	g	0.61	0.52	0.45	0.37	0.37	0.20	0.20
Seine net	g	2.31	1.97	1.69	1.40	1.40	0.77	0.77
SUBSYSTEM II								
Pilchard (live weight)	g	226.7	192.7	165.6	137.1	137.1	75.20	75.20
Polystyrene	mg	319.8	271.8	233.6	193.4	193.4	106.1	106.1
Electricity	kWh	3.51E-3	2.98E-3	2.56E-3	2.13E-3	2.13E-3	1.17E-3	1.17E-3
SUBSYSTEM III								
Diesel (hake fishery)	g	--	--	--	--	--	238.9	238.9
Light fuel oil (canning)	g	276.8	276.8	276.8	--	--	--	--
Olive oil (canning)	g	35.00	35.00	35.00	--	--	--	--
SUBSYSTEM IV								
Polyethylene	g	0.10	0.10	0.10	--	--	3.55	3.55
Electricity	kWh	0.01	0.01	0.01	0.02	0.02	0.03	0.03
Lorry transport	tkm	0.30	0.30	0.30	0.07	0.07	0.11	0.11
Van transport	kgkm	12.45	12.45	12.45	7.34	7.34	10.13	10.13
SUBSYSTEM V								
Olive oil	mL	--	--	--	9.60	--	13.73	--
Salt	g	--	--	--	0.66	0.66	0.46	0.46
Flour	g	--	--	--	4.66	--	4.58	--
Electricity (cooking)	kWh	--	--	--	0.52	--	0.14	0.12
SUBSYSTEM VI								
Tissue paper	mg	653.9	653.9	653.9	746.3	682.9	835.5	768.9
Water	L	2.06	2.06	2.06	2.35	2.15	2.63	2.42
Soap	mg	544.9	544.9	544.9	621.9	569.1	696.3	640.8
Ferric chloride	mg	0.57	0.57	0.57	0.66	0.60	0.72	0.68
Ferric sulfate	mg	0.42	0.42	0.42	0.48	0.44	0.52	0.49

2.6. Life Cycle Impact Assessment

Results computation was performed using the SimaPro software, version 7.3 (Goedkoop et al. 2010). The selected assessment method to calculate the final midpoint and endpoint results was ReCiPe (Goedkoop et al. 2009). For the endpoint results the hierarchist approach was selected.

3. Results

The total endpoint single score environmental impacts identified in *Scenario A* ranged from 0.52 to 0.58 Pt depending on which of the three residue allocation perspectives was selected, representing a maximum variability of only 11%. The canning stage (Subsystem III) accounted for 91% of the total endpoint impacts, while the fishery (4%) and the remaining subsystems (6%) only accounted for a minor part of the overall impacts. *Scenario B*, in contrast, was identified as the scenario with lowest environmental impacts per FU, 90%-95% lower than those found for *Scenario A* and 70%-83% lower than those for *Scenario C*. Nevertheless, important differences were detected depending on the way in which the fresh pilchards had been cooked in the consumer stage. More specifically, the overall environmental impacts of preparing pilchards on a barbeque (i.e., grilled) were quantified at 2.93E-2 Pt, 45% lower than those linked to the consumption of fried pilchards. In this scenario the main contributor to the overall environmental impact was the fishery stage (45%), followed by the consumption subsystem (24%) and wholesaling and retailing (15%) whenever the pilchards are grilled. However, if the pilchards are fried the consumption stage becomes the main contributor (57%), followed by the fishery stage (25%). Finally, the impacts related to *Scenario C* add up to 1.80E-1 Pt if the hake is fried or 1.75E-1 if the hake is boiled. Impacts in this scenario are dominated by the fuel use intensity of the long lining fleet in Subsystem III and, to a lesser extent, to the fuel combustion in the purse seining fleet and in terrestrial transport.

The impact categories that dominate the majority of the processes analyzed were fossil depletion, climate change and particulate matter formation, demonstrating the high reliance on fossil fuels of the processes analyzed, independently of the scenario. Midpoint results for the three scenarios are shown in Table 2.

Table 2. Total environmental impacts per scenario reported per functional unit (ReCiPe midpoint).

Impact categories	Unit	Scenario A		Energy allocation	Scenario B		Scenario C	
		Economic revenue allocation	Economic savings allocation		Fried pilchards	Grilled pilchards	Fried hake	Boiled hake
Climate change	kg CO ₂ eq	3.36	3.09	2.88	4.71E-1	2.06E-1	1.44	1.38
Ozone depletion	kg CFC-11 eq	7.48E-7	7.32E-7	7.19E-7	2.01E-7	1.75E-7	6.65E-6	6.64E-6
Human toxicity	kg 1,4-DB eq	1.71	1.54	1.40	1.73E-1	9.89E-2	1.80E-1	1.39E-1
Photochemical oxidant formation	kg NMVOC	1.78E-2	1.69E-2	1.62E-2	3.57E-3	2.74E-3	2.09E-2	2.06E-2
Particulate matter formation	kg PM ₁₀ eq	1.20E-2	1.08E-2	9.83E-3	1.22E-3	8.61E-4	5.87E-3	5.72E-3
Ionizing radiation	kg U235 eq	9.18E-1	8.56E-1	8.06E-1	1.57E-1	1.62E-2	1.07E-1	7.33E-2
Terrestrial acidification	kg SO ₂ eq	1.98E-1	1.85E-2	1.75E-2	3.36E-3	1.86E-3	1.53E-2	1.48E-2
Freshwater eutrophication	kg P eq	2.36E-3	2.23E-3	2.13E-3	4.00E-4	2.31E-5	2.26E-4	6.73E-5
Marine eutrophication	kg N eq	1.94E-3	1.91E-2	1.89E-2	2.87E-3	9.07E-4	3.53E-3	9.14E-4
Terrestrial ecotoxicity	kg 1,4-DB eq	7.60E-2	7.59E-2	7.59E-2	-7.21E-4	5.42E-4	-1.81E-3	2.06E-4
Freshwater ecotoxicity	kg 1,4-DB eq	1.41E-1	1.23E-1	1.08E-1	2.78E-2	1.75E-3	6.68E-3	3.58E-3
Marine ecotoxicity	kg 1,4-DB eq	2.02E-1	1.82E-1	1.67E-1	6.06E-3	2.61E-3	4.97E-2	4.87E-4
Agricultural land occupation	m ² a	3.94	3.93	3.92	3.02E-2	1.06E-1	2.36E-2	3.50E-2
Urban land occupation	m ² a	7.57E-2	7.19E-2	6.88E-2	2.78E-3	1.95E-3	3.72E-3	3.15E-3
Natural land transformation	m ²	5.92E-3	5.89E-3	5.85E-3	1.10E-4	7.83E-5	5.13E-4	5.08E-4
Water depletion	m ³	4.89E-1	4.87E-1	4.85E-1	1.85E-1	3.34E-3	2.64E-2	5.40E-3
Mineral depletion	kg Fe eq	6.10	5.20	4.49	3.33E-2	3.99E-2	2.57E-2	1.10E-2
Fossil depletion	kg oil eq	1.36	1.28	1.22	1.27E-1	5.54E-2	3.90E-1	3.78E-1

4. Discussion

Environmental impacts in *Scenario A* are strongly influenced by the operations occurring in the canning stage (Subsystem III). The combustion of fuel-oil, the use of packaging materials or the impacts related to the life-cycle of olive oil are all important contributors in this stage. However, the production and use of tin for canning is the main source of environmental impacts, especially in terms of climate change and fossil depletion. Tin impacts, that were modelled according to the ecoinvent® database, are known for the high degree of uncertainty (Classen et al. 2007). Having said this, in the current study these uncertainties were minimized by including recent recycling rates for tin in Spain. Therefore, it is quite obvious, as pointed out in previous studies (Hospido et al. 2006), that a change in the container for canned pilchard could be a convenient improvement action, as long as this measure does not imply a burden in sales due to consumer preferences (Calvo 2013).

The use of olive oil in the cans also presented high environmental impacts, although in this case the impacts were fairly evenly distributed between different stages of production (fertilizers, pesticides, refining, etc...). Hence, integrated minimization of impacts schemes will be necessary in the olive oil producing sector to reduce impacts in this particular operation (Iraldo et al. 2014). Finally, the fuelling of the fishing vessels, especially in *Scenario C*, in which the long liners constitute an important source of environmental impacts, was also identified as a main carrier of environmental burdens. Consequently, appropriate fuel optimization schemes or changes in the energy carrier of the vessels should be analyzed (Bengtsson et al. 2012).

Comparison for the different supply chains monitored in this study was performed with care, since there are some methodological issues that must be taken into consideration. For instance, there are a series of characteristics, such as the shelf life of the products, or the food waste they generate throughout the chains that can vary enormously. However, the lack of data and the assumption that the supply chains were centered in Galicia, a coastal region in which the arrival of fresh fish is done on a daily basis (unlike other landlocked areas in which the shelf life of fresh seafood is reduced considerably) manages to minimize the effect of this issue. Figure 2 shows the direct endpoint single score environmental impacts for each of the processes analyzed, showing a clear dominance of *Scenario A* (all three alternatives) in terms of overall environmental burdens. Nevertheless, it should be noted that the methodological assumptions regarding allocation in the canning phase imply considerable final impacts, although not sufficient to reduce the impact of canned pilchard to the level of *Scenarios B* or *C*. Consequently, it appears that the consumption of the three main ways in which the pilchard raw material is finally consumed by the general public presents three completely different patterns in terms of environmental burdens: i) *Scenario A* presents a high energy use in the processing stage, due to the use of different packaging material -namely tin- as well as the use of electricity and logistics; ii) *Scenario B* presents a very low environmental impact, which is in line with the fresh consumption of other small-pelagic fish (Ramos et al. 2011; Avadí et al. 2014); and iii) *Scenario C* presents a high energy intensiveness, which implies that the final environmental profile of consuming hake is among the highest in the literature (Vázquez-Rowe et al. 2012; Avadí and Fréon 2013).

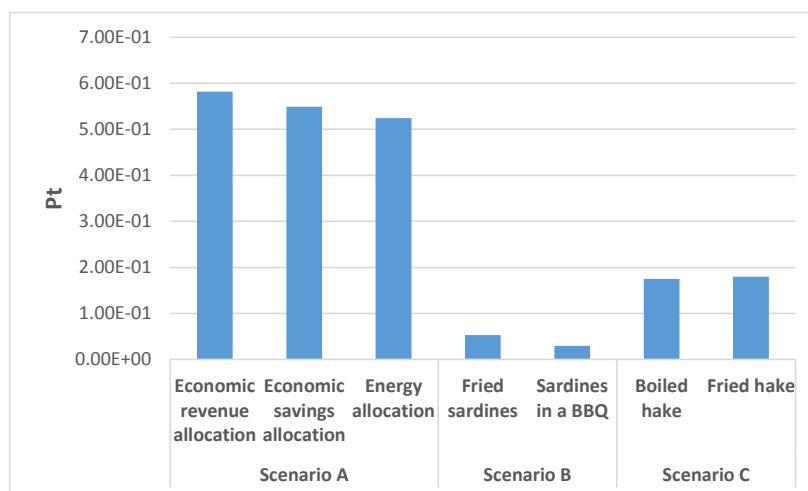


Figure 2. Endpoint single score environmental impact results for the selected scenarios (assessment method: ReCiPe endpoint H/H).

While the results when analyzed in subsystems do not show major surprises in terms of environmental impacts as compared to previous studies available in the literature, to the best of our knowledge the current study is the first attempt to follow the entire life-cycle of seafood products, including consumption, EOL of wastes and human excretion providing an extended view of a variety of different supply chains based on pilchard extraction. Interestingly, the cooking, consumption and EOL stage of the different products in households did not appear to be a major factor affecting the comparability of the three scenarios. However, whenever each scenario is analyzed depending on cooking options, the preparation of fried fresh hake or pilchard showed increased environmental impacts than when other cooking options were considered, such as grilling or boiling, demonstrating that consumer behavior can also have an important impact on the final profile of the products (Vázquez-Rowe et al. 2013b).

Having said this, it is important to highlight that the comparison between cooking methods was done with a fixed weighting of damage categories. Hence, the ReCiPe hierarchist single score values reported in this study imply a 40% weighting of ecosystem damage categories (land use and toxicity categories, together with acidification and climate change), 30% for human health categories (which include climate change (partially, ozone depletion or human toxicity) and 30% for resources (mineral and fossil depletion). However, the use of the MIXTRI 2.0 model, developed by Doka (2011) was selected in order to analyze how different weighting possibilities may lead to variable final results (Hofstetter et al. 1999). In fact, given the high use of energy in the fisheries and transportation stages of the systems analyzed, as well as the use of important amounts of tin in the canned pilchard processing phase, it is arguable that the resources damage category should be weighted higher. Hence, Figure 3, using an uncertainty interval of 35% due to the numerous assumptions considered and described in section 2, represents the Mixing Triangles for Scenarios B and C. In the first place, the results for Scenario A show dominance for the energy allocation perspective. While this is barely surprising due to the allocation assumptions included in each perspective, implying that lower values of inputs and outputs are allocated to most of the processing stage in the energy perspective, the results do confirm the importance of methodological assumptions. However, these results were not represented in Figure 3 since they do not represent different consumption pattern options. Secondly, for fresh consumption of pilchard, the triangle showed complete dominance of grilled pilchard despite the high uncertainty range considered. Finally, for Scenario C the results showed that the relative dominance of boiled hake is highly constrained by the different sources of uncertainty underlying the calculations. While the results presented in the Mixing Triangles do not provide any further findings, they do demonstrate the strong dominance in environmental impacts for certain consumption patterns of one single raw product and consumer behavior trends. Consequently, beyond the relevant findings in terms of improvement actions that can be undergone in the different production systems, these results could be potentially used to drive consumer awareness policies by policy-makers with the aim of improving the environmental sustainability of human diets.

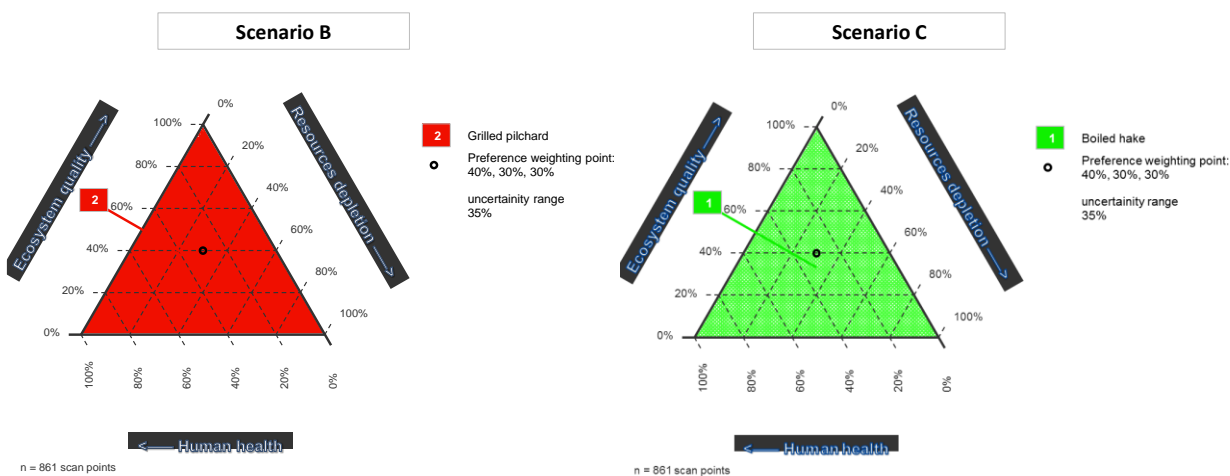


Figure 3. Weighting triangle matrix for different spreading techniques in Scenarios B and C.

5. Conclusion

The results presented in this study suggest that consumer choices in terms of how to intake a specific raw material can have important consequences on environmental impacts. For instance, the consumption of fresh round pilchard implied environmental impacts up to 95% lower than if the pilchard is consumed in cans. In addition, as pointed out in a previous study by Vázquez-Rowe et al. (2013b), cooking methods can also determine to a great extent the amount of environmental impact produced by the analyzed system.

Therefore, we argue that the analysis of the entire life-cycle of seafood products can provide important additional information for policy-makers, retailers, processors and consumers regarding sustainable seafood consumption patterns. In other words, while the extraction of a specific raw material can drive the main environmental profile of a final product, the on-land stages can also have an important role when it comes to mitigating or augmenting the final footprint of these products.

Nevertheless, future research should focus on analyzing these patterns at a broader scale -including the complex wholesaling and retailing networks that occur in the seafood sector- as a way to steer upcoming seafood and general food policies, as well as increasing awareness among consumers regarding the important role that their decision-making can have on the final environmental impact of seafood products.

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