Critical review of allocation rules – the case of Finnish rainbow trout

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ABSTRACT

In life cycle assessments (LCAs) one of the fundamental methodological choices that needs to be made is allocation, especially in multiple-output systems. The difficulty with allocation is that it usually has an ambiguous basis and, thus, damages the credibility of LCA results. Allocation solutions are easily influenced by perspectives and worldviews of the analyst, and there are arguments as to whether, for instance, allocation methods, such as economic, biophysical or mass-based allocations, are suited to different case studies and decision-making situations. Therefore, rules for different multiple-output situations are needed. While there are LCA guidelines that provide rules for different multiple-output situations, they do not fulfill their purpose, being susceptible to interpretation and/or enabling different allocation choices. This is demonstrated here with an attributional LCA case study of one tonne of Finnish rainbow trout fillet.

Keywords: LCA guidelines, allocation, harmonization, rainbow trout

1. Introduction

One of the most argued about methodological choices in LCA is allocation, especially in multiple-output systems where allocation is needed between by-products (see e.g. Azapagic & Clift, 1999). Many studies have indicated that allocation can substantially influence the results, and the choice of allocation method usually has an ambiguous basis and, thus damages the credibility of LCA (see e.g. Curran, 2007; Reap et al., 2008). Allocation decisions are easily influenced by the perspectives and worldview of the analyst, and thus there are arguments as to whether, for instance, economic, biophysical or mass-based allocations are suitable in different case studies and decision-making situations. There are several ways to make allocations and different practices exist among LCA studies and also among LCA guidelines. While many of the recent LCA studies address multiple-output situations and emphasize the importance of the chosen allocation method, the choice of methods raises continuous debate within the research community. Guidelines, such as PAS2050 (PAS2050:2011, 2011) and the GHG-protocol (WRI/WBCSD, 2011), aim at providing a more unambiguous basis for LCA studies, also providing rules to solve multiple-output system situations using allocation. While such guidelines have been available for a while, only a few critical reviews have been published that estimate the success rate of LCA guidelines (see e.g. Ekvall & Finnveden, 2001). To our knowledge there have not been any reviews specifically targeting guideline allocation rules. The main objective here is to review critically the allocation rules and study the differences in recommendations of existing LCA guidelines for multiple-output situations, and, as an outcome, the possible differences in the final LCA results.

We chose Finnish rainbow trout fillet as our case product to study the existing LCA guidelines for multiple-output situations. The choice was made for three important reasons. Firstly, Finnish rainbow trout is the most cultivated food fish in Finland. In Finland, rainbow trout cultivation began to increase in the early 1980s and currently the production volume is around 12 million kilos per year, representing around 89 % of the total volume of fish cultivated in Finland (FGFRI, 2012). Secondly, in Finnish circumstances, the main environmental problem caused by fish cultivation is aquatic eutrophication. It is estimated that in Finland around 2 % of total aquatic phosphorous emissions and 1 % of total aquatic nitrogen emissions come from rainbow trout cultivation (Grönroos et al., 2006). In addition, climate impacts of rainbow trout are also an interesting subject of study because rainbow trout is considered to be a substitute for red meat, which is known for its high carbon footprint. Lastly, rainbow trout is an interesting case product because the production chain of rainbow trout has several multiple-output situations, for instance, between fish fillet and by-products of gutting and filleting. The most common multiple-output situations in seafood LCAs are between target fish and by-catch (capture fisheries), feed ingredients, by-products such as roe and by-products of gutting and filleting when the fish is processed.

During the past ten years there have been several LCA studies on seafood products and the methodologies for solving the multiple-output situations have varied. For instance, Ziegler et al. (2003) used economic allocation for cod. Meanwhile, Eyjólfsdóttir et al. (2003) allocated all environmental loads to filleting in fish processing in the LCA of cod. Winther et al. (2009) used mass allocation for seafood and Ayer & Tyedmers (2009) used system expansion for salmon, where fish processing waste replaced fertilizers. Allocation choices need to be made also between feed ingredients because many of the ingredients come from multiple-output situations. The choices for solving these multiple-output situations have varied among studies: Papatryphon et al. (2004) used economic allocation, Winther et al. (2009) chose mass allocation, and Ayer & Tyedmers (2009) used gross energy content. In general, the most used allocation methods for seafood LCAs are mass and economic allocation, but gross energy content and system expansion are also used in some studies (Ayer et al., 2007; Parker, 2012).

2. Methods

2.1. Functional unit, system boundaries and multiple-output situations

In this study we chose to do an attributional LCA study and the functional unit was one tonne of skinless rainbow trout fillet. The studied impact classes were climate change and aquatic eutrophication. The system boundaries included production of feed raw materials, production of feed, hatchery, farming, processing, packing, and transport (see Figure 1). Fish fillet, besides roe, is the only component for human consumption and the mass of the fillet is 52 % of the initial weight of the fish. The by-products of the process come from gutting and filleting and from roe. The by-products of gutting and filleting are sold to feed processing plants and used further as feed for fur-farming animals. The rainbow trout feed is a mixture of fish meal and oil (mainly sprat, eel and sandeel) and vegetable raw material, mainly soybean meal.

There are several relevant multiple-output situations in the LCA of cultivated rainbow trout. We chose to focus on the four main multiple-output situations (Figure 1):

1) fish meal and oil (both components of rainbow trout feed; ratio is 1:3)
2) soybean meal and oil (soybean meal is a component of rainbow trout feed)
3) round fish (whole fish) and roe
4) fish fillet and by-products of gutting and filleting

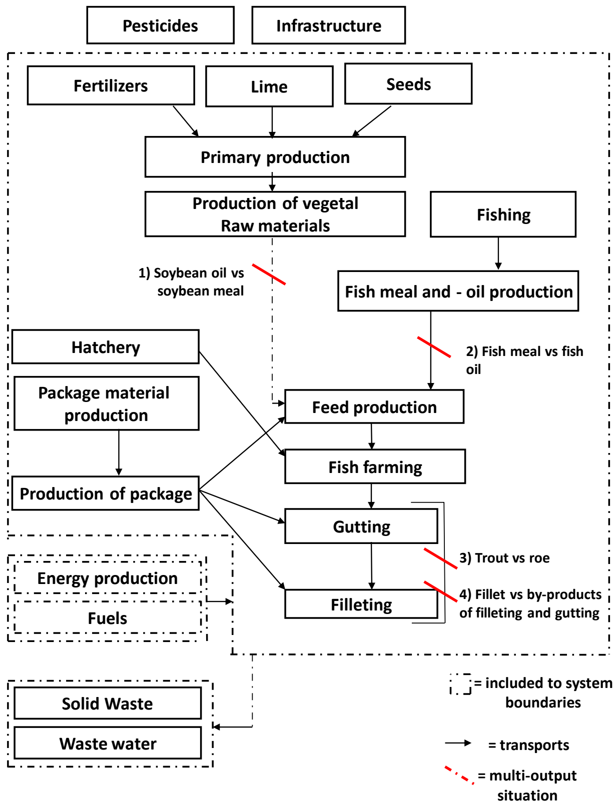

Figure 1. Multiple-output situations and system boundaries for Finnish rainbow trout.

2.2. Data sources

Rainbow trout production volumes and amounts of feed used were based on Finnish statistics and personal interviews (FGRFI, 2013; Kallioniemi, 2009, 2010). The data source of hatcheries was based on a single Finnish fish farming company (Puttonen, 2011) and the data for the nutrient emissions of the fish farm were based on official statistics (Environment Institute of South-West Finland). The fuel consumption of the boat traffic related to fish farming and electricity consumption for the fish farming were obtained from the pilot projects of the Finnish Game and Fisheries Institute (RKTL) (Kankainen et al., 2007, Setälä et al., 2009). The Plastics Europe database was used for the life cycle inventory data for polyethylene, polypropylene and polystyrene and the inventory data of the processing of the polystyrene into boxes used in fish transport. The material inputs for cultivation of one tonne of rainbow trout (round fish, before processing) are presented in Table 1.

The data for fish meal and fish oil production were based on data from a Danish producer (confidential). The modeling of the fish raw material production was based on the LCA Food-database. The inventory data for soybean cultivation were obtained from the Ecoinvent database (Jungbluth et al., 2007) and from da Silva et al. (2010).

Table 1. Energy and material inputs for production of Finnish Rainbow trout. One tonne of round fish.

Material input	
Light fuel oil, l/t	22
Electricity consumption, kWh/t	206
Nylon (Polyamid 6-6), kg/t	5.2
Polyethylene Terephthalate, kg/t	2.2
Polyethylene (HDPE), kg/t	5.8
Concrete, kg/t	13
Light fuel oil, l/t	22

2.3. Sensitivity analysis for allocation methods

In our study we built a basic case where the main four multiple-output situations were solved using allocation methods that we considered to be the most appropriate and systematic for each situation. The substitution method was not considered in the basic case because of a high level of uncertainty and because of arguments that the substitution method is not suitable for attributional LCA studies (Curran, 2007; Heijungs & Guinée, 2007). Furthermore, due to lack of practical examples of physical causality (see e.g. Schau & Magerholm Fet, 2008) we did not consider it here.

In the basic case, economic allocation was chosen for multiple-output situations between soybean oil and meal, round fish and roe, and fish fillet and by-products of gutting and filleting. In the case of soybean oil and meal, the economic value of oil is three times that of meal (FAO, 2011; Jungbluth et al., 2007) and since the products are produced for different purposes, economic allocation was chosen. In the situation between round fish and roe, roe is a very important by-product, having higher economic value (FGRFI, 2013), and thus we decided to use economic allocation. We chose to use economic allocation also between fish fillet and fish by-products of gutting and filleting because while the by-products of gutting and filleting represent around half of the weight of the fish, their economic value is very low. Furthermore, by-products of gutting and filleting would not be produced without also producing the fish fillet, and thus in our opinion more emissions should be allocated to the fillet. All in all, mass allocation was used only between fish meal and oil where mass allocation was chosen because both are of similar economic value and are used for the same purpose – as rainbow trout feed.

Besides the basic case we did a sensitivity analysis where we varied the methods to solve multiple-output situations and compared the results with those for the basic case. In addition to mass and economic allocation, the other methods used were 100-0 allocation, where all emissions were allocated to fish fillet, and a substitution method. Substitution was used between fillet and by-products of gutting and filleting. Both the processing waste from Atlantic salmon processing and captured Baltic herring from the Baltic Sea are used for fur animal feed, and thus the by-products of gutting and filleting of Finnish rainbow trout could replace both Baltic herring and the residues of Atlantic salmon processing. However, the use of Atlantic salmon processing waste as a substitute is problematic because allocation is also needed between Atlantic salmon fillet and its by-products. It should be discussed further whether the substitution method is possible if the substitute is derived using allocation. A second alternative is to assume that the by-products of rainbow trout processing replace Baltic herring, where no further allocation is needed. In this study we used the latter substitute, Baltic herring, because it does not require further allocation. What is interesting about Baltic herring is that it has negative eutrophication impact because fishing removes nutrients from the Baltic Sea.

The chosen LCA guidelines for our comparative study were ISO 14040/44 (ISO 14040, 2006; ISO 14044, 2006), ILCD-handbook (ILCD, 2010), GHG-protocol (WRI/WBCSD, 2011), PAS standard for seafood products (PAS 2050-2, 2012) and PCR Basic Module for seafood products (PCR, 2010). Only the given allocation rules of each guideline were applied.

3. Results

3.1. Basic case and sensitivity analysis

The carbon footprint of rainbow trout fillet was 4.3 t CO2-eq/t of fillet when using the basic case to solve the multiple-output situations. The sensitivity analysis showed a range of 2.3-5.2 t CO2-eq/t of fillet. The lowest result was received when only mass-based allocation was used and was highest when all was allocated to the fillet. The results of eutrophication impact were partly similar to those for carbon footprint. The eutrophication impact was 38 kg PO4-eq/t of fillet in the basic case, while when mass allocation was used, the eutrophication impact was 22 kg PO4-eq/t of fillet, and when everything was allocated to the fillet, the eutrophication impact was over 45 kg PO4-eq/t of fillet. When substitution methodology was used, the eutrophication impact was 57 kg PO4-eq/t of fillet, because fewer nutrients were removed from the Baltic Sea with captured Baltic herring. So, as a result from the sensitivity analysis, allocation had a marked effect on the final results of the LCA for Finnish rainbow trout. The sensitivity analysis showed that the most important multiple-output situations is allocation between fillet and by-products of gutting and filleting, where mass allocation halves the emissions compared with economic allocation.

3.2. Comparative study of guideline allocation rules

Overall, as shown in Table 2, the LCA results varied greatly within and among the LCA guidelines. The comparative study of allocation rules of the chosen LCA guidelines is based on our interpretation of the guidelines. To improve the transparency of results we have also explained our interpretations here.

The ISO-standard recommends substitution and that is why it was chosen when viable for multiple-output situations between fillet and by-products of gutting and filleting. The other multiple-output situations were solved using both mass and economic allocation because the standard does not recommend one over the other (ISO 14040, 2006; ISO 14044, 2006).

In applying the ILCD-handbook guidelines, substitution is not allowed in attributional LCAs. In attributional LCAs the handbook recommends avoiding allocation or solving it using physical-causal relationships, but neither was viable and therefore the third option, economic allocation, was chosen for all multiple-output situations when using the ILCD-handbook (ILCD, 2010).

The GHG Protocol substitution method was not used between fillet and the by-products of fish gutting and filleting because while the protocol recommends substitution over allocation, it states that it has to be known exactly what product is replaced and in our study it was not evident that Baltic herring was the appropriate substitute. In other multiple-output situations both mass and economic allocation were used because the Protocol does not clearly recommend one over the other (WRI/WBCSD, 2011).

In applying the PAS standard for seafood products, avoiding allocation was not a possibility, and thus the second option, mass allocation, was chosen. Furthermore, substitution was used both between fillet and the by-products of fish gutting and filleting (PAS 2050-2, 2012).

The PCR Basic Module for seafood products (PCR, 2010) recommends mass allocation. However, the choice of mass allocation was not obvious because the Supporting Annexes of PCRs state that low-value by-products should be regarded as waste and nothing should be allocated to the low-value product (EPD, 2008). However, because of the difficulties in interpreting the instructions and because of the substantial effect on the results, we decided to present both results, where emissions were first allocated to by-products of gutting and filleting based on mass, and secondly where no emissions were allocated to by-products of gutting and filleting.

Table 2. The carbon footprint (CFP) and eutrophication impact of one tonne of Finnish rainbow trout when the only variant is the allocation method based on recommendations of different LCA guidelines.

Allocation recommendation based on:	Recommended allocation method	Carbon footprint (kg CO_2-eq/ kg fillet)	Eutrophication (kg PO_4^{3}-eq/ t fillet)
ILCD-handbook	Economic	4.2	38
ISO 14040/44	Physical (mass) – Economic + Substitution (by products of gutting and filleting)	4.1 – 4.3	38 – 57
GHG Protocol	Physical (mass) – Economic	2.4 – 4.3	- (only CFP)
PAS2050-2	Mass + Substitution (by products of gutting and filleting)	4.1	- (only CFP)
PCR Basic Module for seafood products	Mass – Mass but emissions are not allocated to by-products of gutting and filleting	2.4 – 4.4	22–39

4. Discussion and conclusion

Seafood LCAs use various allocation methods and the LCA guidelines aim at providing more unambiguous rules for different multiple-output situations. In this study we did a comparative study for different LCA guidelines and interpreted the allocation rules. To our surprise it proved quite difficult to interpret guideline allocation rules even with substantial expertise – having conducted several food LCAs during past two decades. Another surprise was the variation in allocation rules within and among the current LCA guidelines. If our interpretations of the guidelines are accurate, the results vary greatly when using different recommendations, even when the only variant is choice of allocation method. Moreover, while it was not studied here, it is possible that other methodological recommendations (based on the LCA guidelines) could result in much wider variation in the results.

Application of the substitution method was also challenging. The right replacement product was not self-evident. The choice of replacement product for the by-products of gutting and filleting would have a major impact on our comparative study of guidelines. When assuming that processing waste of rainbow trout replaces Baltic herring, the eutrophication impact of fillet rises sharply because fishing of Baltic herring would actually reduce nutrients in the Baltic Sea. Overall, one of the main conclusions is that one has to be careful when using the substitution method. For instance, the GHG Protocol does not recommend substitution when there is uncertainty in defining the substitute (WRI/WBCSD, 2011).

Generally, both the sensitivity analysis and standard comparisons show that allocation has a marked effect on the final results of the LCA for Finnish rainbow trout fillet. When using mainly economic allocation, the environmental impact of a trout fillet can almost double compared with the situation where mainly mass allocation is used. One good partial solution to avoid misunderstandings and improve comparability of LCA studies is to provide arguments for the chosen allocation methods and to conduct a sensitivity analysis – presenting the results of the sensitivity analysis when communicating the final results of the LCA studies. Additionally, our study shows that because the LCA guidelines studied differ from each other they can also be interpreted differently. To reduce the ambiguity of LCA studies we suggest that more work needs to be done to improve recommendations for multiple-output situations and to harmonize the current LCA guidelines.

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https://portal.mtt.fi/portal/page/portal/mtt/hankkeet/foodprint/laskentasuositus/Suositus_071112_Final.pdf

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