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System expansions to handle co-products of renewable materials.

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Abstract

The production of most renewable materials involves co-products. Traditionally, the environmental impacts have been allocated between the different co-products according to a more or less arbitrary allocation ratio. Following the new ISO requirements, and based on SETAC recommendations, allocation shall be avoided whenever possible. It has been the general belief that avoiding allocation through system expansion was not always possible for co-products from renewable material production, since the substitutions involved were believed to be too complex, difficult to determine, and sometimes involving endless regressions. However, these perceived problems can be solved by applying a stringent procedure for identifying the affected processes, earlier developed and presented by the author. This paper shows a number of case studies on renewable materials where allocations have been avoided through system expansion. Examples include the notoriously difficult problems of agricultural or industrial by-products applied as fodder (e.g. rapeseed cake, which substitutes soybean production, which again has oil as a by-product) or fertiliser (e.g. organic manure), the co-products from a cow (meat, milk, butter etc.), and the secondary functions of forestry and agriculture (e.g. maintaining rural income, amenity values such as maintenance of landscapes for recreation).

1. Introduction

The production of most renewable materials involves co-products. Traditionally, the environmental impacts have been allocated between the different co-products according to a more or less arbitrary allocation ratio.

The idea that co-product allocation can be avoided by system expansion has been put forward by Tillman et al. (1991) in respect to waste incineration, and more generally by Heintz & Baisnee (1992). It was given a prominent place in the procedure of ISO 14041, where it reads: "Step 1: Whereever possible, allocation should be avoided by: 1) dividing the unit process to be allocated into two or more subprocesses and collecting the input and output data related to these subprocesses; 2) expanding the product system to include the additional functions related to the coproducts…"

Although avoiding allocation is seen as the preferable option, it has been the general belief that avoiding allocation through system expansion was not always possible for co-products from renewable material production, since the substitutions involved were believed to be too complex, difficult to determine, and sometimes involving endless regressions.

However, these perceived problems can be solved by adapting a stringent procedure for identifying the affected processes, earlier presented in Weidema et al. (1999), leading to the conclusion that allocation can (and shall) always be avoided in prospective life cycle assessments.

2. The procedure

Figure 1 shows how the co-producing process has one determining product (product A), i.e. the product that determines the production volume of that process. This is not necessarily the product used in the specific life cycle study. In figure 1, also just one co-product is shown, but in practice there may be any number of co-products, while at any given moment there can be only one determining product.

That a product is determining the production volume of a process, is the same as saying that this process will be affected by a change in demand for this product. How to identify the processes affected by a change in demand (which is also the processes to be included in a prospective life cycle study) has been shown in Weidema et al. (1999) and the procedure is applied in the examples section 3 of the present paper.

To say that there can be only one determining product at any given moment, is not the same as saying that the other co-products are not of importance. That the co-products can obtain a certain price on the market may well be a precondition for the process to expand its production volume. But when this precondition is fulfilled, it is still only a change in demand for the determining product that will be able to affect the production volume of the process. For example, out of the total income of growing sunflowers, 63% comes from selling the oil and 37% from selling the protein-containing pressing cake as animal fodder. Thus, it is unlikely that more sunflowers would be grown if it were not possible to sell additional sunflower pressing cakes. Yet, it is not the demand for fodder cakes that determines the production of sunflowers, since an increased demand for protein can be met at a lower cost by producing soy beans. Thus, the determining product for sunflowers is the sunflower oil, which is in demand for its particular composition of fatty acids.

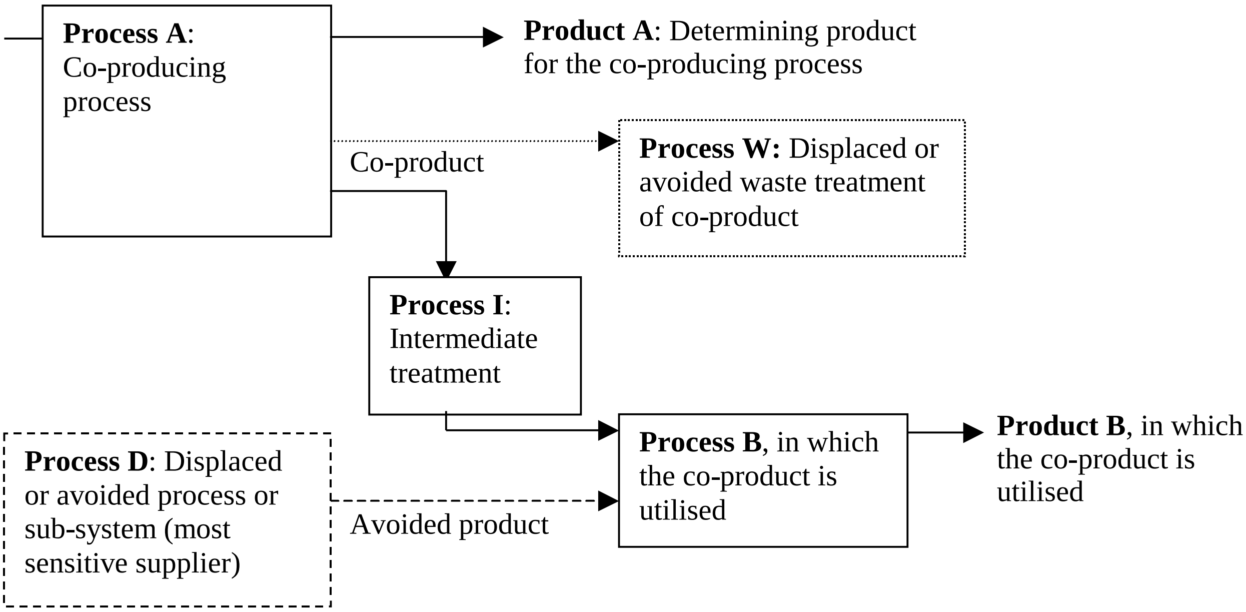

Figure 1. Model for describing system expansion and delimitation in relation to co-production

Performing a system expansion in relation to co-products is exactly to identify how the production volume of the processes in figure 1 will be affected by a change in demand for the product that is used by the life cycle study in question (both when this is the determining product for the co-producing process (A) and when it is the product in which the co-product is utilised (B)). The answer to this question can be summarised in four simple rules:

1) *The co-producing process shall be ascribed fully (100%) to the determining product for this process (product A).*
2) *Under the conditions that the non-determining co-products are fully utilised in other processes and actually displaces other products there, product A shall be credited for the processes, which are displaced by the other co-products, while the intermediate treatment (and other possible changes in the further life cycles in which the co-products are used, which are a consequence of differences in the co-products and the displaced products) shall be ascribed to product A.*

If the two conditions stated in rule no. 2 are not fulfilled, rule no. 3 and 4 apply, respectively:

3) *When a non-determining co-product are not utilised fully (i.e. when part of it must be regarded as a waste), but at least partly displaces another product, the intermediate treatment shall be ascribed to product B, while* product *B is credited for the avoided waste treatment of the co-product.*
4) *When a non-determining co-product is not displacing other products, all processes in the entire life cycle of the co-product shall be fully ascribed to product A.*

More detailed arguments for the presented rules can be found in Weidema (1999) and Weidema (2001).

3. Case 1: By-products applied as fodder

Many of the less valuable co-products of the food industry are used as animal fodder, and typically there is no alternative way to produce the food product in question. For example, wheat bread can only be produced from wheat, which is milled to flour, while the other fractions (germ, bran, and husk) are used for animal fodder (with the exception of a very small part that is used in speciality products for human consumption). In this case, there is little doubt that the flour is the only co-product that can provide adequate economic revenue to change the production volume of the milling process (and the wheat production), and that the flour is therefore the determining product.

The protein by-products displace the most sensitive protein source, which is soy meal. This can be determined from the linear regression models used by enterprises producing mixed feeds. By keeping all industrial fodder by-products constant except one protein component at a time, it can be shown that a change in this one protein component will be balanced by a change in soybean input. This can be explained by the fact that soybean is the only protein crop (aside from grains) for which the protein is the main product. Some substitution between grain and protein concentrates is possible, as determined by their relative prices. However, within the next 10 years, the price of soybeans is expected to be well below the price of grain.

Besides protein, soy production yields the co-product soy oil. The displaced soy oil production will thus lead to an increase in the most sensitive alternative supply of edible oil. This can be determined from the price relations between alternative oil crops. Different oil crops are grown to obtain different fatty acid compositions and thus cannot substitute each other completely. The more expensive oil crops will be grown to the extent that there is a market demand for their specific fatty acid composition, while the remaining demand will be met by the cheapest edible oil. Under the current market conditions, rape is the cheapest edible oil with a fatty acid composition that makes it substitutable with soy oil in most applications.

This gives then an additional amount of rape seed protein as a co-product, which then again displaces more soy protein and so on. Since only two global markets are involved (the fodder protein market and the edible oil market), this loop can easily be closed. The calculation is based on the relative content of oil and protein in the two products. Since soy beans yields half as much oil as protein, while rape yields just the opposite ratio, it can easily be seen that for every amount of soy protein displaced, half the amount of oil is displaced, leading to the displacement of again half of this amount of protein, i.e. 25% of the original amount of protein.

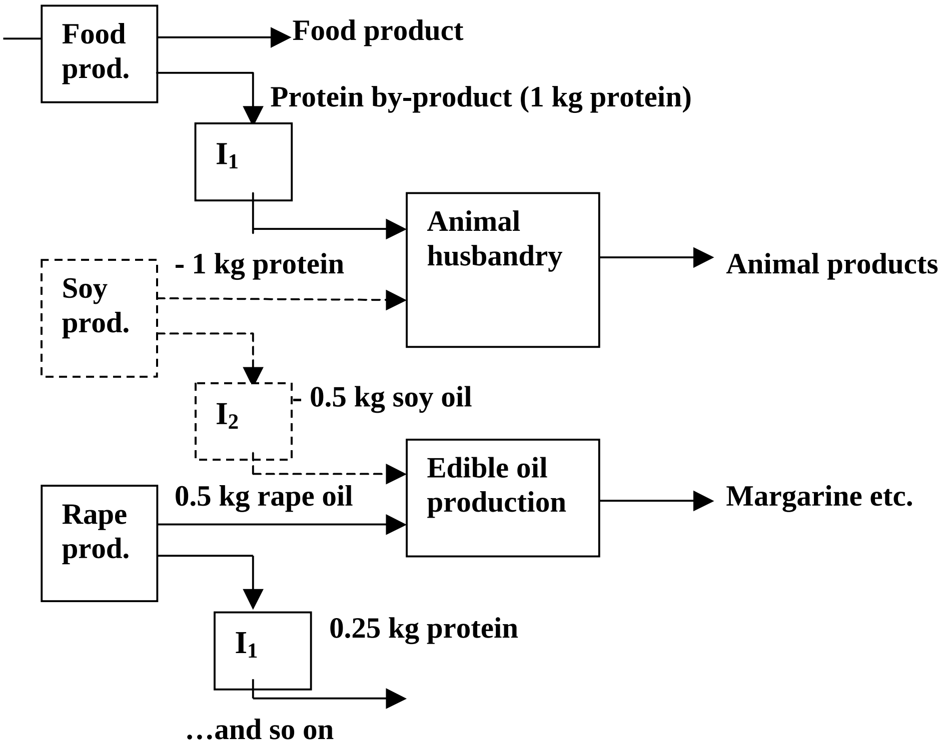

Figure 2. System expansion for protein by-products

By iteration, it can be calculated that 1 kg of raw protein in a food industry by-product requires the following system expansion:

- a *reduction* in volume of soy protein of $1 + 0.25 + 0.25^2 + 0.25^3 + \ldots = 1.33$ kg raw protein, which is equivalent to 3.9 kg soy beans (at a protein content of 34%), and

- an *increase* in rape production of $0.25 + 0.25^2 + 0.25^3 + \ldots = 0.33$ kg raw protein, which is equivalent to 1.66 kg rape seed (at a protein content of 20%).

Similar calculations can be made for energy rich by-products, such as molasses, which affect the most sensitive energy source, which is typically grain. By-products applied as fertiliser (e.g. organic manure) will displace the most sensitive supply of artificial fertiliser. For nitrogen fertiliser in Europe, the market is in decline, which implies that the most sensitive supplier is an older plant in Eastern Europe or Greece.

4. Case 2: Co-products of a milking cow

The main income from a milking cow is the milk, which must be seen as the determining product. The by-product meat will displace separate production from meat cattle (or meat production from other animals depending on the substitutability). The hide is only partly used in leather production and a change in demand will therefore lead to a change in the amount of hide for less specific purposes (similar to waste treatment).

At the dairy, the milk is split into numerous fractions of which the consumer milk fraction is the dominating. Due to the milk quotas in Europe, changes in demand for one milk fraction will not affect the primary production, but are adjusted for by changing the outputs of the other fractions. The ultimately affected production is the most flexible fraction: milk powder.

5. Case 3: Secondary functions of forestry and agriculture

Agriculture and forestry has a number of secondary functions, such as maintaining rural income and maintenance of landscapes for recreation. As the name implies, these functions are typically secondary compared to the production of physical products. Thus, the secondary functions may be regarded as non-determining co-products, while the physical product (e.g. wheat or wood) is typically the determining product. The demand for the physical product can change either as a result of changes in the market or changes in crop specific subsidies. In both cases, the fulfilment of the secondary functions is affected (e.g. causing changes in rural income or landscape maintenance compared to the desired output of these functions). This change will either be counteracted by alternative measures, implying a case for rule 2 (see section 2), or it will be accepted, implying a case for rule 4. The affected alternative measure (i.e. the most sensitive measure for supporting rural income or for landscape maintenance, respectively) depends on the current policies in the specific situation.

In some situations, the so-called secondary functions may in fact be the primary concern, e.g. when rural income support is administered per land area or when landscape maintenance is rewarded without requirements to what crops should be grown. If this source of income leads to changes in the production, the subsequent change in composition of product output may be one of the side-effects that has to be accounted for by including the alternative production displaced. As in the case of fodder by-products above, this may involve a number of subsequent changes on different markets.

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