Consequential and attributional modeling in life cycle assessment of food production systems

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ABSTRACT

The aim is to contribute to a deeper understanding of the differences between the consequential (cLCA) and attributional (aLCA) modeling approaches and to show how the choice between cLCA and aLCA in some cases can be decisive for the outcome of an LCA. We present cradle-to-gate CO_2-eq. emissions (carbon footprint) of barley, soybean meal and palm oil and discuss the differences between the cLCA and aLCA methodologies and results.

Keywords: Consequential LCA, Attributional LCA, Life Cycle Inventory modeling

1. Introduction

Is consequential (cLCA) or attributional (aLCA) modeling the correct choice for life cycle assessment? This is among the most discussed questions within the LCA community during the last 10-15 years. Although an ISO standard was launched several years ago, massive disagreement between LCA practitioners still exists, as the norm does not distinguish between them. The two most important differences between cLCA and aLCA are the handling of multi-functional processes (allocation versus substitution) and whether or not constrained suppliers are included in the market mixes. According to Weidema and Moreno (2013) a comparison between cLCA and aLCA results in ecoinvent showed that more than 12% of the LCIs deviate with more than a factor 2. In this article we discuss the cradle-to-gate CO_2-eq. emissions (carbon footprint) of several food products, namely barley, soybean meal and palm oil. The aim is to contribute to a deeper understanding of the differences between the two modeling approaches and to show how the choice between cLCA and aLCA in some cases can be decisive for the outcome of an LCA.

2. Methods

LCA data on barley, soybean meal and palm oil from Dalgaard et al. (2014) were used to investigate how the modeling approach affects the carbon footprint results. Four different modeling approaches were used to calculate carbon footprint of milk in the study of Dalgaard et al. (2014) and the data are from 2005. The four approaches consist of consequential modeling and three different versions of attributional modeling. However, in the current study, only data from the consequential modeling and the attributional version named ‘allocation/average modeling’ are presented for simplicity. The by-products are accounted for by substitution (cLCA) and price allocation (aLCA). In cLCA only flexible suppliers are included, whereas in aLCA also constrained suppliers are included. Constrained suppliers are suppliers that do not respond to a change in demand for a certain product. In order to reduce complexity, the effects related to indirect land use changes are excluded. For more details on modeling assumptions, see Schmidt and Dalgaard (2012) and Dalgaard and Schmidt (2012).

3. Results

The differences in carbon footprint depending on the applied modeling approach are presented in Figure 1. Both barley, soybean meal and palm oil are products deriving from multi-functional processes. The by-products are the following: Straw from barley production, soybean oil from soybean meal production and palm kernel meal and empty fresh fruit bunches from palm oil production. The allocation in the attributional modeling is based on product prices from 2005. The differences in carbon footprint of barley are and presented in more detail in Figure 2. The cLCA carbon footprint for soybean meal is negative (-0.40 kg CO_2-eq.) because the by-product soybean oil substitutes palm oil on the market (Dalgaard 2008), and the saved emissions from palm oil production more than counterbalance the emissions from soybean production and processing. The difference between the two carbon footprints of palm oil is small. This is mainly because the by-product allocation factors are small in aLCA, due to the low value of the by-products (e.g. palm kernel meal, fresh fruit bunches), so that the oil is attributed most of the impact. In cLCA the by-products have low avoided emissions.

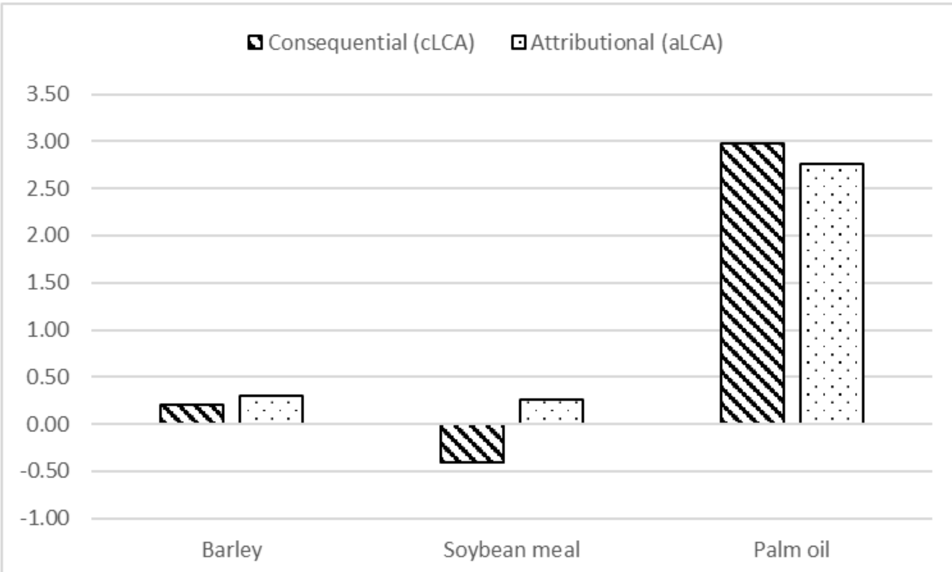

Figure 1. Carbon footprint of barley, soybean meal and palm oil using respectively cLCA and aLCA modeling. Unit: Kg CO_2-eq. per kg.

In this case the production of barley is a multi-functional process from which both barley and straw/energy are produced. According to Statistics Denmark (2012) 75% of the straw was removed from the grain fields in 2005. Barley and straw constitute respectively 75% and 25% of the biological material removed from the field. In cLCA this is handled by substitution. All emissions from the production of barley/straw are ascribed to the main product barley and afterwards the emissions from the saved energy caused by incineration of straw are deducted.

The CFs are 0.21 (cLCA) and 0.30 (aLCA) kg CO_2-eq. per kg barley. The contributions from each part of the product chain are presented in Figure 2. The emissions from the field, fertilizers, diesel and services & capital goods are lower for aLCA mainly because 40% of the GHG-emissions are allocated to straw. However, this is more than counterbalanced by the avoided energy production in cLCA, which is deducted from the barley and reduce the GHG-emission by 0.30 kg CO_2-eq.

However, the emissions related to fertilizer production are 65% lower in the aLCA scenario compared to the cLCA scenario. The main reason for the lower emissions is, as described earlier, that 40% of the emissions from fertilizer production are ascribed to the straw. The remaining 25% of difference between cLCA and aLCA is mainly caused by the differences in fertilizer market mixes used in the cLCA and aLCA. Both manure and mineral fertilizers are applied to the field during the barley cultivation. In cLCA the manure applied to the fields for fertilization is considered as constrained and excluded from the fertilizer mix, whereas in aLCA both manure and mineral fertilizer are included in the mix. The inventory for manure in aLCA is from a multi-functional process from which both manure, beef, milk and energy are produced. Energy is from incineration of fallen cattle. The emissions from the multi-functional process are distributed between the four co-products and only 1% is ascribed to the manure. This results in considerable lower carbon footprint per kg N for manure compared to mineral fertilizer and that contributes significantly to the lower GHG emissions from barley cultivation, when applying the aLCA methodology.

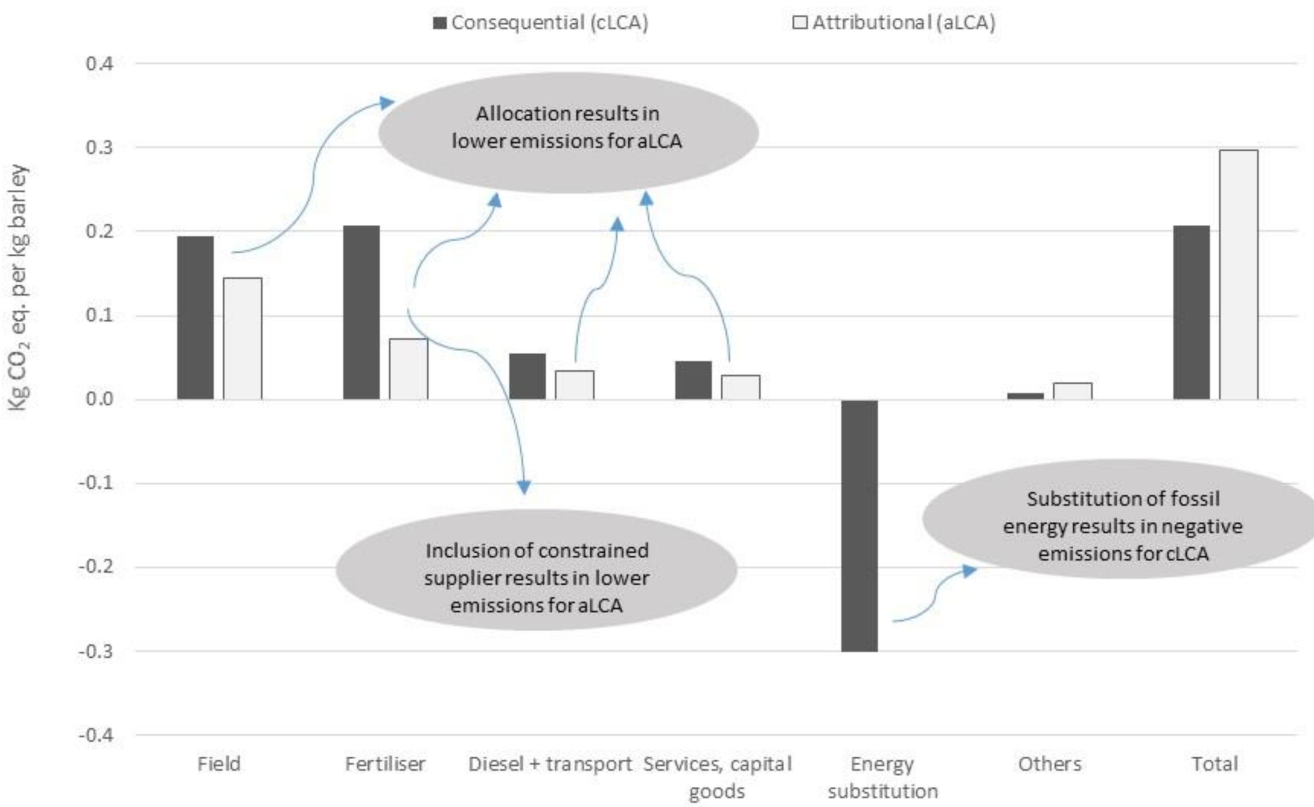

Figure 2. Contribution to GHG emissions from different parts of the barley production chain. Unit: Kg CO_2-eq. per kg barley.

4. Discussion and conclusion

The cLCA and aLCA carbon footprints above show that the main reasons for the differences in results are:

- Substitution (cLCA) versus allocation (aLCA) for handling of multi-functional processes
- Exclusion of constrained suppliers from market mix (cLCA) versus inclusion of constrained suppliers in market mix (aLCA)

Substitution is fundamentally different from allocation. In the barley case it is obvious that the production of barley results in straw production, which again results in saved fossil energy. On the other hand the allocation is a rather artificial way to overcome the multi-functional process issue. In this case, the allocation is based on prices of electricity and heat, but it could as well be straw prices or mass of barley and straw respectively. The definition of allocation method is normative and not based on reality. However, in cLCA the definition of the type of energy substituted can also be challenging for the less experienced cLCA practitioner. If the farmer uses the straw for energy production the carbon footprint of barley will be lower regardless which of the modeling approaches are applied.

Constrained suppliers are excluded in the cLCA modeling, but included in the aLCA modeling. Misleading results might be a consequence of including constrained suppliers in a market mix. In the example with barley the market mix for fertilizer includes manure. If advice to the barley producers was given on the basis of the aLCA, an increased use of manure instead of mineral fertilizer would obviously be a good solution, because the carbon footprint of N in manure is lower than the average N in mineral fertilizer. But in reality, a shift from use of mineral fertilizer to manure will not increase manure production but rather the production of mineral fertilizer. Farmers have cattle because they want to sell milk or beef and not manure, thus an increased demand for manure does not result in more manure production.

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