CONSEQUENTIAL AND ATTRIBUTIONAL MODELING IN LIFE CYCLE ASSESSMENT OF FOOD PRODUCTION SYSTEMS

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INTRODUCTION

- Is consequential (cLCA) or attributional (aLCA) modeling the correct choice for life cycle assessment? massive disagreement between LCA practitioners still exists on this subject.
- The ISO standards 14040 and 14044 do not distinguish between them.

OBJECTIVE

- To contribute to a deeper understanding of the differences between aLCA and cLCA in food systems, showing how the choice can be decisive for the outcome of an LCA.
- We do this by discussing the carbon footprint of barley, soybean meal and palm oil.

METHODS

- Inventory data for barley (Denmark), soybean meal (Brazil) and palm oil (Malaysia) from [**1**] were used.
- In cLCA modeling the by-products are accounted for by substitution, and constrained suppliers (those who do not respond to a change in demand for a certain product) are excluded.
- In aLCA price allocation is used and constrained suppliers are included.
- To reduce complexity, the effects related to land use change are excluded.
- For more details on modeling assumptions, see [**2**] and [**3**].

Table 1. Main differences between aLCA and cLCA.

	aLCA	cLCA
Standardisation	Rule-based (e.g. ILCD Handbook)	ISO 14040/44/49
Goal & Scope	Descriptive	Consequences of changes
Completeness / System delimitation	Complete global system of activities, but no rebound effects. Linking of both constrained and unconstrained activities.	Only affected parts. Only unconstrained activities are linked.
Reference flow	Produced by scaling the existing average markets and suppliers	Produced by scaling the most likely suppliers to be affected by a change in demand
Elasticity of supply	Full, except for joint production	Full, except for constrained supplies
Long-term constraints	Ignored	Identified / captured
Handling of joint production	Partitioning (Allocation)	Substitution (System expansion)
Market effects	Ignored	Identified / captured
Data	Average	Marginal
Uncertainty	More precise, less accurate	Less precise, but more accurate
Representativeness and relevance for decision-support	Low	High

Table 2. Products and by-products in production of barley, soybean meal and crude palm oil

	Barley (DK)	Soybean meal (BR)	Palm oil (MY)
By products	Heat and electricity from straw	Soybean oil	Palm kernel meal (animal feed)
cLCA modelling: Displaced activities by by-products	Production of heat and electricity (DK)	Vegetable oil (Palm oil, MY)	Animal feed protein (soybean meal, BR) Animal feed energy (Barley, UA) Fertiliser (GLO)
aLCA modelling:			
- Allocation to main product	60%	68%	81%
- Allocation to by-products	40%	32%	19%

RESULTS AND DISCUSSION

Carbon footprint of barley, soybean meal and palm oil

- In barley, the footprint for aLCA is 43% higher than for cLCA. More details are provided in **figure 2**.
- The cLCA footprint for soybean meal is negative because the by-product soybean oil substitutes palm oil on the market, and this credit from palm oil production is higher than the emissions from soybean production and processing.
- The difference between footprints of palm oil is small, mainly because the by-product allocation factors are small in aLCA, due to the low value of the by-products so that the oil is attributed most of the impact. In cLCA the by-products have low avoided emissions.

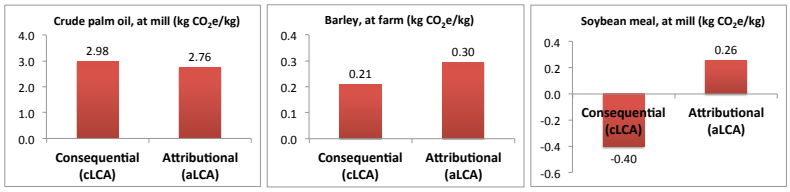

Figure 1. Carbon footprints of barley, soybean meal and palm oil according to consequential and attributional modelling.

Detailed contribution analysis for barley

- In cLCA there is a credit from use of straw as fuel. In aLCA there are no credits .
- In aLCA, many processes obtain lower footprints, because straw used as fuel gets 40% of the burdens.
- In fertilizer production aLCA has an even lower footprint due to the low impact of manure. In cLCA manure is not considered in the fertilizer mix as it is constrained.

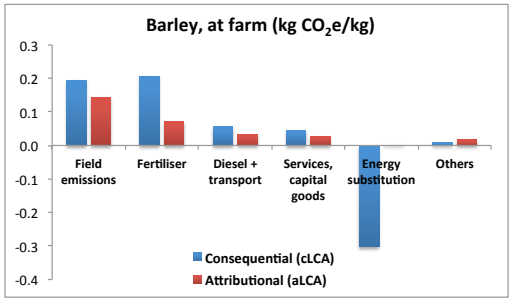

Figure 2. Contribution analysis for the carbon footprint of barley, according to consequential and attributional modelling.

CONCLUSIONS

- Results of aLCA and cLCA can be very different in some cases, affecting the outcome of a study. In some cases differences can be smaller.
- The main differences between aLCA and cLCA are related to substitutions, allocation, and to the inclusion vs. exclusion of constrained suppliers.
- Inclusion of constrained suppliers in LCA can be misleading for decision making, e.g. demanding more manure because it has lower emissions than mineral fertilizer will not lead to more manure being produced, as it is constrained by definition.

References: **[1]** Dalgaard et al. (2014) Generic model for calculating carbon footprint of milk using four differ-ent LCA modeling approaches. J Cleaner Prod, 73, 15: 146-153. **[2]** Dalgaard R, Schmidt JH (2012) National and farm level carbon footprint of milk - Life cycle inventory for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus, Denmark. **[3]** Schmidt JH, Dalgaard R (2012) National and farm level carbon footprint of milk - Methodology and results for Danish and Swedish milk 2005 at farm gate. Arla Foods, Aarhus, Denmark.