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# Attributional or consequential Life Cycle Assessment: A matter of social responsibility

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ABSTRACT

Results of Life Cycle Assessment (LCA) are critically dependent on the system boundaries, notably the choice of attributional or consequential modelling. Published LCA studies rarely specify and justify their modelling choices. Since LCA studies are typically performed within the context of social responsibility and product life cycle management, this article investigates the relationship between social responsibility paradigms and the system modelling choices in LCA. We identify three different social responsibility paradigms: Value chain responsibility, Supply chain responsibility and Consequential responsibility. We point out that while there is no generally right or wrong choice of system model, each responsibility paradigm implies a specific matching system model. We then argue that all responsibility paradigms ultimately imply a consequential perspective, namely that of responding to the concerns of the system stakeholders. Although value or supply chains are systems defined without concern for consequences, and thus may include activities that the decision maker cannot influence, the chosen system is still analysed and assessed by accounting for its social consequences, and it is for these consequences that social responsibility is then taken. We argue that it is inconsistent to exclude consequences of own actions (i.e. the consequential system) while including consequences from actions of others in value chain or supply chain. We thus conclude that a consistent socially responsible decision-maker *must* always take responsibility for the activities in the consequential product life cycle and *may* additionally take responsibility for the consequences of other activities in the value chain or supply chain. We end the article with recommendations on reporting on LCA system models that are more specific than those of the current LCA standards.



## 1. Introduction

This article presents the results of an investigation into the relationship between social responsibility paradigms and the system modelling choices in LCA. This investigation was motivated by the widespread lack of specification and justification of the modelling choices made in published LCA studies, which leads to confusion when LCAs on the same product arrive at different results and conclusions. Since LCA studies are typically performed within the context of social responsibility and product life cycle management, the results of our investigation may contribute to improved clarity on and justifications of the modelling choices in LCA. The research methods applied are critical review and deductive logic from the first principles of formal ethics.

The current literature, which we review in Section 2, discuss different principles for allocation of responsibility within a value chain, but do this with the implicit premise that the relevant system for which responsibility is taken is the value chain, i.e. the economically allocated fraction of either purchases or sales. However, delimiting the system to that of value chain already implies an allocation of responsibility. Based on the definition of social responsibility and its concept of "sphere of influence" as well as the literature on system delimitation in LCA, we point out that any choice of system boundary necessarily involves the application of a normative rule.

In Section 3, we identify three different system types: value chains, supply chains and consequential product life cycles, each representing a specific social responsibility paradigm: value chain responsibility, supply chain responsibility and consequential

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responsibility, respectively. We describe and exemplify each of these system types and their rules for system boundary closure.

In our discussion, Section 4, we argue that it is possible to take responsibility for more than one system perspective at a time, thus combining systems additively, while the selective use or mixing of different system modelling rules in the assessment of a single system leads to obscuring and shifting of responsibility. We then argue that all responsibility paradigms ultimately imply a consequential perspective, namely that of responding to the concerns of the system stakeholders. We argue that it is inconsistent for a socially responsible decision maker to exclude consequences of own actions (i.e. the consequential life cycle) while including consequences from actions of others in the value chain or supply chain.

We thus conclude, in Section 5, that assessment of social responsibility *must* always include the consequential product life cycle and *may* additionally include consequences of other activities in the value chain or supply chain, and call for increased transparency in reporting of modelling choices and system boundaries for LCA studies.

This paper does not investigate the initial motivations for taking social responsibility, but exclusively investigates the consequences of a consistent application of social responsibility to LCA modelling.

## 2. Review of the current literature

### 2.1. Principles for allocation of responsibility within a value chain

In the current literature, allocation of responsibility for environmental impacts has mainly been discussed in the context of the global regulation of greenhouse gas emissions. In this literature, it has been pointed out that the allocation of responsibility to nations exclusively for their direct territorial emissions ignores the important role of final consumption as the main driver for the emissions (Kondo et al., 1998; Eder and Narodoslawsky, 1999; Munksgaard and Pedersen, 2001; Peters and Hertwich, 2008). This *territorial responsibility* (often referred to using the more ambiguous term “producer responsibility”) creates perverse incentives for “carbon leakage”, including the outsourcing of emissions to countries with lower commitments (Pedersen and de Haan, 2006), and thus for an inefficient allocation of resources. As an alternative to territorial responsibility, Life Cycle Assessment (LCA) and the closely related Environmentally Extended Input-Output Analysis (EEIOA) provide a solution based on *consumption responsibility*, allocating to the consumers of a country all the emissions caused by the production and consumption of that country's *final demand* for goods and services. This implies an incentive for customers to purchase from the value chain with the least impacts and overcomes the problems of the territorial allocation. A third alternative is *income responsibility* (term coined by Marques et al., 2012; first conceptual description by Gallego and Lenzen, 2005), allocating all the emissions generated *downstream* in the value chain, including final consumption and disposal, to the activities that receive income from the value chain, i.e. in proportion to their value added. This implies an incentive for suppliers to compete to supply the sales chain (chain of customers) with the least impacts. As an example, Lenzen and Murray (2010, p. 268) mention:

> “Important contributions to the downstream carbon responsibility of engineers are the emissions they enable through lending their technical skills to run power plants, beef farms, natural gas rigs, and coal mines.”

implying – somewhat counterproductively – that, to reduce their personal responsibility, engineers should stop providing services (e.g. of advice on emission reduction) to the most polluting industries, and instead focus on the least polluting.

Although the discussion of these three responsibility principles (summarized in Table 1) has mainly taken place in the context of global regulation of greenhouse gas emissions, the principles are generally applicable to any environmental aspect of production and consumption.

The relevance and fairness of the three principles outlined above and in Table 1 are discussed in the above-mentioned sources and a number of others (Rodrigues et al., 2006, Lenzen et al., 2007; Rodrigues and Domingos, 2008; Marques et al., 2013). These authors suggest different criteria to determine the appropriate combinations of the consumption and income responsibility principles, based on the premise that both of these principles are legitimate, as formulated by Marques et al. (2013, p. 162):

> “After all, for final consumers (households and government) to purchase goods and services, they must first earn their income (wages, taxes or interests) as suppliers of primary factors of production. Thus, it is as legitimate to account for the emissions generated upstream that are embodied in final demand, as to account for emission, which are enabled downstream by primary inputs.”

One of the proposed criteria is that the responsibility should be allocated to the actors receiving benefit from the transaction and thus indirectly benefit from the environmental damage. While most authors identify the consumers as the ones receiving the benefit, and therefore settles for consumption responsibility, Rodrigues et al. (2006) and Marques et al. (2012) follow Ferng (2003) and regard both consumption and income as benefits. None of the authors give any consideration to consumer and producer surplus as the normal measure of social benefit from a transaction (Mankiw and Taylor, 2006).

Some of the suggested criteria are mutually exclusive. In the case of Rodrigues et al. (2006) even within the same article, requiring both

> “that environmental responsibility should verify a normalization condition, such that the sum of the environmental responsibility of all agents should equal total environmental pressure”

and

> “the indicator should not display wrong signals, only allowing for a decrease in environmental responsibility of an agent if there was a decrease in overall direct environmental pressure” (both quotes on p. 259)

which are mutually exclusive conditions, since the first refers to - and can only be fulfilled in - a steady-state analysis of environmental pressure and the second condition refers to a change in environmental pressure and can only be fulfilled in an analysis of changes, which is not possible in the analysed steady-state system.

Lenzen et al. (2007) claim that their specific shared responsibility allocation approach will provide the same efficiency incentives as a property rights regulation or a tax/subsidy directly targeting the same impacts. However, since the shared responsibility is arbitrarily assigned from the principles, there is no reason to believe that this would incentivise behavioural change in the same way as economic incentives would. Aside from this unsubstantiated claim by Lenzen et al. (2007), none of the above-mentioned authors address the consequences, effectiveness or efficiency of the two modelling principles with respect to achieving a reduction in environmental damage, most explicitly formulated by Lenzen and Murray (2010, p. 264):

**Table 1**
Three principles for allocation of responsibility within a value chain.

| Responsibility principle | Driver | Activity scope | Impacts |
|---|---|---|---|
| Territorial | Activity | Direct | Direct |
| Consumption | Demand | Direct and upstream | Direct and embodied |
| Income | Supply | Direct and downstream | Direct and enabled |

"For the purpose of this article, we take an ex-post perspective, in which actions have occurred, so that the problem of evaluating alternative scenarios does not come up."

Thereby they miss the important point that while a consumer shifting purchase from one unconstrained supplier to another will lead to a consequent shift in production of these suppliers, there is no similar direct consequence of a producer shifting between supplying different customers (if such a shift is at all practically possible), since there is nothing that stops other producers from filling the empty space and supply the abandoned customers, thus resulting in a net zero impact on production and emissions. This asymmetry of power in the value chain is a strong argument for consumption responsibility and against income responsibility, when the purpose is to efficiently stimulate real-life changes.

More importantly for our work here, all the sources mentioned above are based on the premise that the system for which responsibility is taken is the value chain, i.e. the economically allocated fraction of either purchases (consumption responsibility) or sales (income responsibility); see e.g. Rodrigues et al. (2006, p. 259) and Lenzen and Murray (2010, Table 1 on p. 263) for an explicit formulation of this. None of the authors appear to realise that by choosing the value chain as the system under study, they have already made an allocation of responsibility. None of the reviewed articles address the arguments for or the implications of this implicit modelling choice. In this article, we seek to fill this gap by pointing out that *prior* to the discussion on the relevance of the consumption and income responsibility principles and their implied modelling choices, there is a fundamental modelling choice in the delimitation of the system, and that the value chain is only one of these possible delimitations, and not necessarily the most relevant one.

### 2.2. Social responsibility

The concept of social responsibility has developed from its initial formulation as "corporate social responsibility" (Holme and Watts, 2000, p. 10):

"the commitment of business to contribute to sustainable economic development, working with employees, their families, the local community and society at large to improve their quality of life"

to the current ISO 26000 definition in which the "corporate" has fallen away, following the realisation that the concept is equally applicable to all types of organisations:

"responsibility of an organization for the impacts of its decisions and activities on society and the environment, through transparent and ethical behaviour that

- contributes to sustainable development, including health and the welfare of society;
- takes into account the expectations of stakeholders;
- is in compliance with applicable law and consistent with international norms of behaviour; and
- is integrated throughout the organisation and practised in its relationships" (ISO 26000:2010, Clause 2.18)

The term "relationships" in ISO 26000 refers to an organisation's "sphere of influence", defined as the:

"range/extent of political, contractual, economic or other relationships through which an organization has the ability to affect the decisions or activities of individuals or organizations" (ISO 26000:2010, Clause 2.19)

which is further explained in Clause 5.2.3:

"This sphere of influence includes relationships within and beyond an organization's value chain. However, not all of an organization's value chain necessarily falls within its sphere of influence. It can include the formal and informal associations in which it participates, as well as peer organizations or competitors. An organization does not always have a responsibility to exercise influence purely because it has the ability to do so. For instance, it cannot be held responsible for the impacts of other organizations over which it may have some influence if the impact is not a result of its decisions and activities. However, there will be situations where an organization will have a responsibility to exercise influence. These situations are determined by the extent to which an organization's relationship is contributing to negative impacts. There will also be situations where, though an organization does not have a responsibility to exercise influence, it may nevertheless wish, or be asked, to do so voluntarily."

In the report of the Special Representative of the United Nations Secretary-General on the Issue of Human Rights and Transnational Corporations and other Business Enterprises, Ruggie (2008, Clause 4):

"concluded that "sphere of influence" is too broad and ambiguous a concept to define the scope of due diligence with any rigour"

notably because the concept:

"conflates two very different meanings of "influence". One is "impact", where the company's activities or relationships are causing human rights harm. The other is whatever "leverage" a company may have over actors that are causing harm or could prevent harm. Impact falls squarely within the responsibility to respect; leverage may only do so in particular circumstances." (Ruggie, 2008; Clause 12)

In this article we apply insights from the debate on attributional and consequential modelling in LCA to contribute more formal clarity on the different ways to define the sphere of influence for social responsibility.

### 2.3. The unavoidability of a normative system delimitation in LCA

All economic activities are interlinked through a global network of product flows,[1] which means that there is no *objective* way to delimit an organisation's sphere of influence as any discrete part of the world's activities. From the perspective of a specific organisation, all other economic activities in the world can be found as contributing a small share to the value chain or supply chain of the organisation. Likewise, when looking at consequences forward in time, the activities of any specific organisation will to some extent contribute to or impact on a large part of the other economic activities in the world. In this network perspective, there is no end to the sphere of influence of an organisation. Any practically applicable delimitation will therefore require the application of a normative rule.

In the context of life cycle inventory analysis (LCI), Ekvall (2000) suggests that different normative rules for system delimitation can be linked to different ethical positions. Notably, teleological situation ethics (consequentialism) can be linked to the effect-oriented (consequential) LCI methodology and deontological rule ethics can be linked to accounting, thus suggesting that the latter may be relevant in a context where the actor wishes to support, be part of, or otherwise be associated with what is deemed to be a “good” system, or to be dissociated with what is deemed to be a “bad” system. However, Ekvall (2000) acknowledges that an application of deontological rule ethics would require an agreement on what is regarded as “being associated with” and therefore concludes that “Further research is required before an operational LCA methodology can be derived from rule ethics”. In a comment to Ekvall, Weidema (2003) states:

> “Nevertheless, it is natural that a commissioner of a life cycle study may feel that it is more relevant to study the processes in the immediate supply chain than those actually affected by the product substitutions. It is important to clarify whether the interest of the commissioner is really in the environmental impacts of products (i.e. in LCA) or more in the environmental impacts of the supply chain as such, since the latter interest may be better handled through supply chain management.” (Weidema, 2003, p. 18)

In this article, we build on and expand these ideas.

## 3. Value chains, supply chains and product life cycles

In this section, we describe three different system types (value chains, supply chains and product life cycles) that we have identified as representing three different social responsibility paradigms: Value chain responsibility, Supply chain responsibility and Consequential responsibility (see also Fig. 1). The two first system types (value chains and supply chains) have become known in LCA as attributional models, while the product life cycle is a consequential model. These terms were originally coined at an international workshop on electricity data for LCI in 2001, where it was stated that attributional and consequential modelling are intended to answer different questions (Curran et al., 2005):

- Attributional LCI aims to answer “how are environmentally things (pollutants, resources, and exchanges among processes) flowing within the chosen temporal window”?
- Consequential LCI aims to answer “how will flows change in response to decisions”?

The two modelling approaches have been defined in the glossary of the Shonan database guidelines (Sonnemann and Vigon, 2011) as:

- Attributional approach: System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.
- Consequential approach: System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.

Note that the three system types and their corresponding social responsibility paradigms have no immediate relation to the three principles for allocation of responsibility within the value chain, reviewed in section 2. In the discussion in section 4.1 we will furthermore argue that the discussion on allocation of responsibility is irrelevant for LCA because it is possible to take responsibility for systems from more than one responsibility perspective at a time and responsibility need not be divided. That is, contrary to Gallego and Lenzen (2005), we argue that several actors can assume full responsibility, so that responsibility is not a conserved quantity like mass.

### 3.1. Value chain responsibility

The term “value chain” was coined by Porter (1985) in the context of analysing competitive advantage. In his definition: “The value chain … views the firm as being a collection of discrete but related production functions, …defined as activities” (Porter, 1985, p. 39). When linked to the value chains of suppliers and buyers, “A firm's value chain is embedded in a larger stream of activities that I term the *value system*” (Porter, 1985, p. 34). While the term “value system” may be the most correct to signify such an interlinked system of activities, it may also easily be confused with the same term used in ethics as a system of consistent values used for the purpose of ethical integrity.[2] We therefore use the term *“value chain”* to signify ***a system of interlinked activities that contribute value added to a product***, and implicitly “value chain responsibility” to signify taking responsibility for this system.

In practice, the value chain of an activity is identified by tracing each cost item input to an activity backwards in the chain. The cost for one (purchasing) activity, is a revenue for the supplying activity. For each activity, a part of the revenue leaks out as payments to employees and entrepreneurs, taxes, and rents (together known as “value added”). In a closed steady-state system, all the original revenue must eventually leave the system as value added, thus providing a clear delimitation of the activities included in the system. When summing up all the value added over a value chain, you obtain the “life cycle cost”, which is equal to the revenue of the analysed activity (Moreau and Weidema, 2015). When joint production activities are partitioned to obtain the value chain for a single product, the accounting balance (cost = revenue) for each single-product activity is maintained by partitioning each input proportionally to the share that each joint product has in the overall revenue. In LCA jargon this is known as “revenue allocation” or more loosely as “economic allocation” (Ardente and Cellura, 2012). Note that unless there is complete proportionality between the physical properties and the revenues for the joint products, the resulting systems will not be physically balanced (Weidema, 2017b). In general, a value chain will therefore not reflect the

[1] We use the term “product” to denote both goods and services.

[2] We generally use the term value in the meaning of “economic value”, i.e. marginal values expressed in monetary units, as opposed to absolute ethical values.

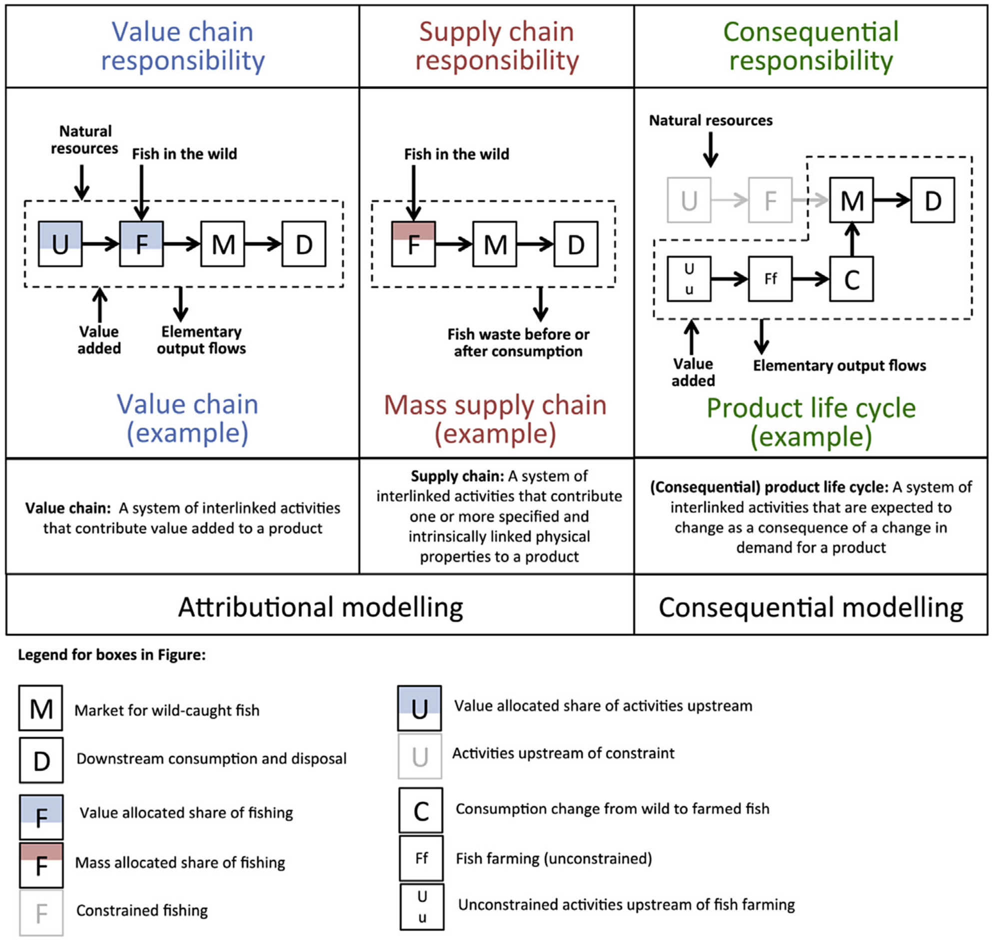


**Fig. 1.** The three identified responsibility paradigms and the three corresponding system types illustrated by the example of wild-caught fish.

physical causalities of purchasing a product.

As an example of a value chain, we can describe the value chain for wild caught fish: The revenue from the sale of the target fish goes to the fishing activity, which also has a valuable by-catch. The valuable inputs to the fishing, i.e. those that are accounted as cost items, are the different value added items (payments to employees and entrepreneurs, taxes, and rents for the fishing rights) and mainly energy inputs and the fishing gear and the fishing vessel. The non-value added items link to further activities, such as oil extraction, steel manufacture and so on, in the end including a little of practically all activities in the world. For each of the upstream activities, a share is allocated to the target fish output in proportion to the share of the revenue for the target fish in the total revenue (from target fish and by-catch). The value added items of each activity are system external inputs, which are not followed further upstream, and this thus provides closure to the system. Note that also the fish, before being caught, is not followed further upstream, because as a wild resource it has no value beyond the rent paid for the fishing rights, which is a transfer from the user to the (public or private) resource owner and part of the value added.

### 3.2. Supply chain responsibility

The term “supply chain” is sometimes used as a synonym for what we above called the value chain. However, in its more strict usage, the term refers to the logistic chain of suppliers to an activity, and can be used with reference to both physical supplies and supplies of services or information. It is increasingly being used in relation to traceability, where a customer wishes to know the exact origin of a product (Norton et al., 2014).

Obviously, the physical supply chain of materials and parts may be very different from the supply chain of information, energy or other services to the same activity. For an unambiguous identification, it is therefore necessary to specify a supply chain in terms of the physical (as opposed to economic) properties it supplies, e.g. mass, energy, or a specific elemental content. If two properties are not intrinsically linked, the supply chain of one property may at some point disengage from the supply chain of the other property, and it then becomes impossible to say which of the two chains should be followed. We thus define a supply chain as *a system of interlinked activities that contribute one or more specified and intrinsically linked physical properties to a product*. Obviously, it is possible to overlay several supply chains, depending on the purpose of the analysis, and how many properties the decision maker wishes to take responsibility for.

In practice, the supply chain of an activity is identified by tracing the investigated property backwards in the chain. The input of one activity is either the output of a supplying activity or an external input to the system. In a closed steady-state system, all the input must eventually enter the system as what, in LCA jargon, are called “elementary” flows, i.e. flows that come from the environment without previous human transformation, thus providing a clear delimitation of the activities included in the system. Taking the property mass as example, the sum of all mass inputs over a mass supply chain will equal the mass of the analysed product and all wastes and by-products from the system. When joint production activities are partitioned to obtain the supply chain for a single product, the mass balance for each single-product activity is maintained by partitioning each input proportionally to the share that each joint product has in the overall mass output. In LCA jargon this is known as "mass allocation". To provide a physically consistent and balanced system, each specific supply chain analysis can only trace one specific property (or several intrinsically linked properties). Note that unless there is complete proportionality between the analysed physical property and the revenues for the joint products, the accounting balance (cost = revenue) will be lost. In general, a supply chain will therefore not reflect the economic causalities of purchasing a product.

We use the mass of wild caught fish to provide an example of a supply chain: The mass of the target fish can be traced back to the fishing activity, again having a valuable by-catch and non-valuable discards. The mass of the wild fish input is the system external input, which is not followed further upstream, and this thus provides closure to the system. The input mass is allocated proportionally between target fish, by-catch and discards on a mass basis. Other inputs to the fishing activity, such as fishing gear, fishing vessel, etc. are often treated as service inputs (the service of providing fishing capacity) and therefore do not provide any net inputs to the mass of the supply chain. While it is obvious that such capital goods are necessary for the production of the primary product, they are not necessary for the mass balance or traceability of the primary product.

### 3.3. Consequential responsibility

The consequentialist idea that actors should be responsible for the consequences (impacts) of their production or consumption actions is fundamental to environmental management systems, as defined by the ISO 14000 series. These systems organise the management of an organisation's significant environmental aspects, which ISO 14001:2015 (Clause 3.2.2) defines as those aspects that have or can have one or more significant environmental impacts. Environmental impacts are in turn defined as a change to the environment (ISO 14001:2015, Clause 3.2.4).

The ISO 14040-series on LCA reflects this in the description of how product life cycles (product systems) are constructed, with respect to intermediate inputs:

> "The supplementary processes to be added to the systems must be those that would actually be involved when switching between the analysed systems. To identify this, it is necessary to know: (…)
>
> - which of the unconstrained suppliers/technologies has the highest or lowest production costs and consequently is the marginal supplier/technology when the demand for the supplementary product is generally decreasing or increasing, respectively." (ISO 14049, Clause 6.4)

and with respect to co-production:

> "The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure:
>
> a) Step 1: Wherever possible, allocation should be avoided by
> - dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or
> - expanding the product system to include the additional functions related to the co-products (…)
>
> The inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input-output relationships and characteristics." (ISO 14044, Clause 4.3.4.2).

What is reflected in these quotes is that the study of (potential) impacts must necessarily imply modelling the *changes* resulting from a (potential) decision. This implies modelling *marginal* changes when the studied changes are small, and *incremental* changes when the changes are larger, as opposed to the average modelling implied in the delimitation of value chains and supply chains.[3] For both marginal and incremental modelling "the supplementary processes to be added to the systems must be those that would actually be involved when switching between the analysed systems" (ISO 14049, Clause 6.4).

In practice, a product life cycle is identified by tracing each required product input, physical or monetary, backwards through the long-term marginal suppliers of each product, i.e., the suppliers that will change their production capacity in response to an accumulated change in demand for the product. The resulting product life cycle is thus demand-driven and based on consumption responsibility, cf. the literature reviewed in section 2 of this article.

When co-productions are modelled as described in the quote from ISO 14044 above, i.e. by subdivision of combined production and by placing dependent joint[4] by-products as negative inputs instead of as positive outputs, thus expanding the product system with the displaced substitutes of the joint by-products, all physical and economic balances remain intact. In parallel to what we found for the value chain, the value added summed over all activities in a product life cycle equals the "life cycle cost", and the sum of inputs of each balanceable property (such as dry wet and elemental mass as well as energy) will equal the outputs from the system. In general, a product life cycle will therefore reflect both the physical and economic causalities of purchasing a product.

In parallel to what we found for the value chain, the revenue generated by the original demand must eventually leave the product life cycle as value added, thus providing a clear delimitation of the activities included in the product life cycle. The activities included are limited to those that react to the change in revenue, corresponding to the first-order effects of the original spending. Implicitly, when comparing products with different prices, a consequential model will include first-order price rebound effect, while excluding second order effects, such as changes in consumption patterns that may result from the redistribution of the initial spending on the population groups that receive the primary factor income, or second order effects of stimulating specific activities, such as education, research and technological development (Weidema et al., 2015).[5]

We use the demand for wild caught fish as an example of a product life cycle: A marginal increase in demand for wild caught fish leads to a temporary increase in the price of wild fish and thus

[3] It is remarkable that in the extensive value chain and supply chain literature the concept of the *marginal* value or supply chain does not appear to have played any significant role, although this perspective could have important implications also for these fields.

[4] Subdivision by physical causality is only possible for combined production, where the amounts of the co-products can be varied individually, while this is not the case for joint production.

[5] Such multiplier effects can be – and are – included in distributional equity assessments, social life cycle impact assessment, and dynamic economic models for the study of societal developments, i.e. beyond the normal consequential, first order, steady-state modelling of the consequences of small-scale decisions.

to an increase in revenue of the fishing activity. However, under the current conditions, the increase in revenue does not lead to increased output of wild fish, since the total output of wild fish is currently constrained, partly by quotas, partly by the limited physical amounts that are available for harvesting within the current economic limits. Instead, the marginal increase in the price of wild fish leads the marginal consumer of wild fish to leave the market and substitute with a more affordable next-best unconstrained alternative, typically farmed fish. This increases the revenue to the aquaculture production and increases the output of farmed fish correspondingly.[6] The necessary inputs to aquaculture production are then stimulated and can be linked backwards to further activities in parallel to what was done for the value chain. The difference to the value chain analysis is that the inputs are only linked to marginal, unconstrained suppliers, and when co-products are encountered they are dealt with as described in the quote from ISO 14044 above. As for the value chain analysis, the value added items of each activity are not followed further upstream, thus providing closure to the system. Note that the primary fishing activity is *not* a part of the system, in spite of the system having a net functional output of wild caught fish (the demanded wild fish is actually supplied, but this is due to the marginal consumers renouncing their demand for wild fish and not due to changes in outputs from primary fishing).

What this example illustrates is that, in contrast to the average modelling applied for value and supply chains, consequential product life cycles do not include constrained activities, i.e. activities that do not change their output in response to a change in demand for this output. However, an actor may still want to influence such constrained activities, for example when constrained activities provide the most cost-efficient environmental improvements, or when the constrained activity is part of a value chain or supply chain that the actor wishes to take responsibility for. Since constrained activities cannot be influenced by general changes in demand for their products, it is thus necessary to use other instruments that link the improvements to products of unconstrained activities.

An example could be a food company wishing to change their wild fish supply (a constrained product due to quotas and physical/economic limits) from using bottom trawling to using less environmentally damaging alternatives (longlines, gillnets, pots and traps). One option for the food company would be to introduce a label for fish caught by low-impact gear. Since the *shift* in fishing gear is not constrained, the environmental consequence of consumers buying the labelled product will be 1) the difference in impact between the fish caught with low-impact gear and the "normal" trawl-caught fish, and 2) the additional production of the alternative farmed fish (because the change of fishing gear does not in itself mean that more wild fish is caught). Another option that would *not* require a separate label would be for the food company to publicly promise an increase its sourcing from this low-impact source in some proportion to the purchases of the consumer of the general (unconstrained) goods, thus linking the specific desired changes in the constrained activity to the demand for an unconstrained product.

The literal meaning of responsibility implies that it is delimited to what an organisation is *able to respond to* (Power et al., 2008), i.e. meaningfully act upon and change, cf. Section 2.2 on the concept of "sphere of influence". From this perspective, it can be argued that a socially responsible organisation should not be exclusively concerned with the activities within the specific value chains, supply chains, or product life cycles of the organisation, but rather be responsible for influencing what it *can* influence (cf. the concept of "noblesse oblige", i.e. that with wealth, power and prestige come responsibilities). The socially optimal action for any organisation at any specific point in time is to change the specific activities that provide the currently most cost-efficient environmental improvement, no matter whether these activities show up as important within the specific value chains, supply chains, or product life cycles of the organisation. However, this is still a consequential perspective in the sense that it is concerned with change, i.e. with the impacts of the actions of the organisation – it just does not limit these actions to those narrowly related to the product output. If an organisation decides to actively influence an activity that is not part of its product life cycles, this implies spending economic resources that indirectly are dependent on the revenue obtained from the product life cycles of the organisation, and this spending thus indirectly becomes a part of these product life cycles. Here it should be noted that a unit of analysis could be the product portfolio of an organisation, resulting in an aggregate of several product life cycles. Such a portfolio LCA has also been called "an Organisational LCA" (Blanco et al., 2015).

In line with this idea of responsibility for what can be influenced, it can also be argued that inaction, i.e. the omission of action in a situation where action could have been taken, has consequences. If comparing a change to "business-as-usual", the difference between the two can be expressed either as a consequence of a change (action) or as a consequence of inaction ("business-as-usual").

### 3.4. System cut-offs

As mentioned above, all three system types (value chains, supply chains and product life cycles) have a natural closure, when all of the analysed property has been accounted for as input to the system. The system boundary is thus given by the cut-off rule that the inputs of "elementary flows" are not followed further upstream. No further cut-off rules are required.

However, for some specific delimitations of responsibility, namely in those situations suggested by Ekvall (2000), where an actor wishes to support, be part of, or otherwise be associated with what is deemed to be a "good" system, or to be dissociated with what is deemed to be a "bad" system, Weidema (2003) suggests that an additional cut-off rule could be applied, namely that of tier distance or transactional distance:

> "the concept of "being associated with" is hardly meaningful beyond a few steps backwards or forwards in the supply chain, thus rendering LCA too sophisticated a technique for identifying the relevant associations." (Weidema, 2003, p.18)

## 4. Discussion

### 4.1. Mixed or combined systems: shifting or expanding responsibility?

Many published LCAs have applied a mix of allocation rules, combining revenue allocation, physical allocation, and system expansion within the same system, which of course obscures both how the system boundary is identified and what question the study will be able to answer (Weidema, 2017b). As illustrated by our example of wild caught fish, different system models leave out different activities and place different emphasis on those that are

[6] The constraint on wild fish implies that an increase in output of farmed fish can only be obtained by increasing the share of vegetable protein input in aquaculture. It is also possible that part of the consumers will substitute with other food products, such as chicken, which are also based on vegetable protein.

included, so that a skilful mix of modelling rules can make nearly any undesired activity disappear or lose importance.

Selective application or mixing of different system modelling rules within the same system can therefore only be seen as a way of shifting (away) responsibility. But if the different system models are instead used in combination, the possibility arises of taking responsibility for more than one system perspective at the same time, i.e. expanding rather than shifting responsibility. In contrast to the statement of Gallego and Lenzen (2005) that

> “it is intuitively clear that the responsibility for impacts associated with transactions in a productive system has to be somehow divided between the supplier and the recipient of the respective delivered commodity” (Gallego and Lenzen, 2005, p. 366)

we do not see any arguments suggesting that it is not possible to take responsibility for more than one system perspective at a time, nor any arguments suggesting that responsibility has to be divided when two or more actors take responsibility for the same activity. This view was already put forward by Eder and Narodoslawsky (1999). In this view, the allocation of responsibility becomes irrelevant, and what matters is instead what the co-responsible stakeholders can do about the impacts.

The problem with the allocation of responsibility within a value chain outlined in Section 2.1 and in Table 1 seems to be that responsibility is being allocated according to the actors' ability to influence/change, while the impact is being quantified by a steady-state model, rather than by the marginal product life cycle that is necessary for analysing changes/decisions between alternatives. In the latter, the life cycle impact is that of a product and not of a stakeholder: The life cycle impact is the same for all stakeholders, and need not to be divided.

### 4.2. *Responsibility for improvements*

Social responsibility and environmental management systems imply a responsibility to seek to improve. But if the focus is on responsibility for improvements, why choose a product perspective in the first place? It is important to distinguish between assessment of impacts of products (whether as value chains, supply chains or product life cycles), and assessments of impacts of industries/activities. Assessment of environmental problems of industries can be made without a product perspective. It is misleading to apply a product perspective when addressing industry/activity problems, because the product perspective leaves out relevant issues either by allocation (attributional) or by looking only at the unconstrained activities (consequential). And some of the important issues that should be tackled may lie in either the parts that have been allocated away or in the constrained parts of the industries that cannot be affected by indirect market-based demand changes, but only by incentivising direct changes. In our example of fisheries, an industry analysis would point to trawling as the most environmentally damaging activity. Studies using the attributional value or supply chain of wild caught fish would both allocate a part of the trawling away to the by-products, while the consequential product life cycle would not include trawling at all, except if included explicitly by the decision maker.

Changes to attributional systems have consequences beyond the system boundaries, i.e. in the parts that have been allocated away, or made less important through averaging. Choosing between attributional systems based on their relative impacts implies a disregard for these consequences, and can lead to sub-optimal decisions and even to increases in overall impacts. For example, an attributional study of cow's milk may conclude that impacts per litre of milk should be reduced by increasing the efficiency of the milk output, e.g. by changes in fodder composition. The result would be that the dairy cow system would produce less meat per litre of milk. Since the demand for meat is unchanged, the reduction in meat output from the dairy cow system would have to be compensated by an increase in dedicated meat production by beef cattle, which could lead to an overall increase in environmental impact per litre of milk compared to the original dairy system that substituted more of the dedicated meat production. This consequence of reduced substitution would not be captured by the attributional system because the meat by-product would have been cut-off by allocation. More examples can be found in Weidema (2017a).

If you want to make an improvement to a constrained part of a system, this implies actions that go beyond the consequential product life cycle, but these actions can still be assessed with a consequential model of the specific change. In our example of fisheries, even though the primary fishing is a constrained activity, and therefore not part of the consequential product life cycle, a consequential model can still be used for a separate assessment of the environmental implications of any specific decisions to *improve* the primary fishing activity, such as the shift from bottom trawling to longlines or gillnets. However, it is important to understand that such an improvement in fishing practices will not in itself change the (marginal) life cycle of wild fish products because primary fishery is not part of the life cycle due to the constraints. To link the changed fishing practices to the consumption of the marginal product, a label is required that implies a commitment of the producers to change fishing practices in proportion to the sale of the labelled product.

## 5. Conclusion

### 5.1. *The consequences of responsibility*

We have identified, described and exemplified three different system types: value chains, supply chains and consequential product life cycles, each representing a specific social responsibility paradigm: value chain responsibility, supply chain responsibility and consequential responsibility, respectively. Any choice between these systems will be *normative,* since the global interlinked nature of economic activities leaves no *objective* way to delimit an organisation's social responsibility to any discrete part of the world's activities. It is possible to take responsibility for more than one system perspective at a time, thus combining systems additively, while the selective use or mixing of different system modelling rules within the same system leads to obscuring and shifting of responsibility.

The literal meaning of responsibility implies a focus on consequences that can be meaningfully acted upon and changed, i.e. responding to the concerns of the stakeholders within the sphere of influence of the organisation. This consequentialist idea is also fundamental to social responsibility and environmental management systems, as defined by the ISO 26000 and ISO 14000 series. Even if a system is defined without concern for consequences, and thus includes activities that the decision maker cannot influence, it is the consequences of the chosen system for which responsibility is taken.[7]

Following from the first principles of formal ethics (Gensler,

[7] This can also be seen from the fact that Life Cycle Impact Assessment, i.e. the modelling of the further impact once the elementary flows have left the system, has always been based on marginal analysis, i.e. the additional impact of an additional unit of the elementary flow.

1996) it does not appear to be consistent for a decision maker to exclude consequences of own actions (i.e., the product life cycle) while including consequences from actions of others in the value chain or supply chain.[8] Thus, we conclude that a consistent socially responsible decision-maker *must* always take responsibility for the activities in the consequential product life cycle and *may* additionally take responsibility for consequences of other activities in the value chain or supply chain. The consequential life cycle can be seen as the "impact" part of the sphere of influence discussed in Section 2.2, while the additional activities included from the value or supply chain can be seen as representing the "leverage" part of the sphere of influence.

Assessments of products (whether as value chains, supply chains or product life cycles) are not adequate for identifying important improvement options (hotspots) outside the narrow system boundaries of these assessments. Assessments of products are relevant once hotspots have been identified within the system you have chosen to be responsible for (value chain, supply chain, product life cycle, or the whole world).

In order to avoid burden-shifting and to fulfil the purpose of LCA as a tool for improvements, identified improvement options need to be compared, in order to identify the one that provides the largest improvement. These comparisons are always comparisons of consequences of implementing each of the options. In this context, it is also important to note that a decision to continue *business-as-usual* can also be modelled as a change relative to ceasing the activity (the zero baseline). This implies that a consequential product life cycle model can also be used to assess a single existing activity or product against the zero baseline. Two such separately developed life cycle models may then later be compared.

### 5.2. Communication

Both attributional and consequential system models may be difficult to communicate. Consequential product life cycles only include those activities that change as a result of a decision. This is not always the activities that one would intuitively think, which may make the consequential product life cycles appear counter-intuitive until context is communicated and the model is investigated more in detail. Attributional system models (value chains or supply chains) may at first sight appear simpler to communicate because they follow a more static logic. Communication difficulties appear only at closer examination in the form of the:

- Artificial nature of allocated activities (that have no real-life parallel) and systems (that violate the law of conservation of mass and energy).
- Subjective choices of allocation factors and system boundaries that leave out some of the consequences of the production and consumption of the product.

Ideally, an agreement should be made to use the same system model and database for all product assessments. The arguments provided in this article support an agreement on the consequential life cycle as the default system model that *must* always be used, which *may* then be supplemented by additional, specific, value chain or supply chain related activities.

Published LCA studies rarely specify and justify their modelling choices and system boundaries. To make it possible to interpret LCA results meaningfully, it is necessary that the social responsibility context is clearly communicated, i.e.:

- who is responsible for the analysis and its use (decision maker, stakeholder, analyst, shared responsibility)?
- whether the full consequential product life cycle has been included, specifying any product-related consequences that may have been cut off, and
- whether any additional value chain or supply chain related activities have been included, specifying which or with what allocation rules (allocation keys, point of allocation) and cut-off criteria (tier distance, simple contribution, or specific activities for cumulated contribution).

These reporting requirements are more specific than those of the current LCA standards.

[8] The relevant ethical principle can in everyday language be expressed as "Practice what you preach". This is also known from the parable of the mote and the beam (Matthew 7:1–5).

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