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SOCIAL LCA IN PROGRESS

How to define the system in social life cycle assessments? A critical review of the state of the art and identification of needed developments

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Abstract

Purpose This literature review aims at fostering the use of social life cycle assessment (SLCA) and improving the robustness of the method by focusing on one primordial element: system boundaries definition. Our goal is to provide an overview of methods used to create the product system and the cut-off criteria applied.

Methods We analyse SLCA case studies from peer-reviewed journals and some academic reports published from 2009 until 2015. Amongst the 33 SLCAs identified, 9 are within an life cycle sustainability assessment. We analyse how authors conceptually define the product system and the implications of their different approaches. We also classify and describe the criteria used for cut-off and their justification.

Results and discussion We find that two conceptual views of the system exist, and often coexist, in reviewed case studies; one technical approach, defining life cycle stages in terms of technical processes related by material or energy flows, and one description of the system in socio-economic terms, selecting organisations as system units. Those organisations are where technical processes take place or are the economic actors whose functioning is influenced through market and economic ties by the life cycle of the product (consequentially indirect sources of social impacts). Cut-off criteria are applied in 15 cases. They are mostly qualitative, have a high variability in their justifications and are distributed in four groups: social significance, empirical motivations, identical elements and significant dependency and decision relevancy. Two articles conduct a sensitivity analysis, showing radically different results depending on the conceptual view leading the design of the system. Finally, we see that the conceptual view of the system and applied cut-off criteria depend on the objectives of the assessment, the targeted audience and the methodology chosen to conduct the SLCA.

Conclusions Differing conceptual approaches of the system and very diverse cut-off criteria used are identified in SLCA case studies. This variability allows a better adaptation of studied systems to the objectives of the assessments. Justifications for system boundaries setting is many times lacking or not systematised. A more rigorous documentation of system boundaries setting in future case studies and research is recommended.

Keywords Cut-off · Sensitivity analysis · SLCA · Social LCA · System boundaries · System description

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1 Introduction

Several reviews on the state of the art and challenges in the field of social life cycle assessment (SLCA) have been presented over the last years (Chhipi-Shrestha et al. 2014; Jørgensen et al. 2008; Parent et al. 2010; Wu et al. 2014). They have principally focused on the development of consistent characterisation and life cycle impact assessment (LCIA) methods.

Until now, less attention has been directed to areas such as system boundary delimitation and handling of cut-offs in SLCA. According to the United Nations Environment Programme/Society for Environmental Toxicology and Chemistry (UNEP/SETAC) SLCA Guidelines (Benoît and

Mazijn 2009), system boundaries refer to the determination of which unit processes should be included in the system being assessed. As stated by Lagarde and Macombe (2012), to effectively communicate the criteria for what and who was included in and excluded from the assessment is a major credibility factor. The same authors lift the risk of overlooking indirect effects or externalities caused by the product in focus, although this is one of the principal pillars for the legitimacy of SLCA. Swarr (2009) stated that "Externalities are the zone of conflict, and deciding where to draw the boundary is the fundamental question for sustainability". Thus, little systematisation and transparency in system delimitations can impair estimation of the level of uncertainty linked to gained results, reduce robustness and potential for replicability or cross-study comparisons and, worst of all, harm identification of some of the main impacts caused by the investigated product and thus reduce the relevance of SLCA as a method in the framework of sustainability assessments.

The inherent difficulty in setting of system delimitations is acknowledged in the UNEP/SETAC Life Cycle Initiative SLCA Guidelines (Benoît and Mazijn 2009), hereafter referred to as the Guidelines, stating that "even if we had an unlimited research budget and unlimited time and were omniscient (all-knowing), we could still disagree about what should be included in the boundary of 'a product life cycle' for life cycle assessment". According to the Guidelines, the main reasons behind this are differences in studies' objectives, SLCA practitioners' world-view and previous experiences of modelling. These aspects will always introduce a certain amount of subjectivity in defining system delimitations, yet increasing the necessity for clear definitions, transparency and substantiated justifications of made choices.

Previous environmental LCA (ELCA) studies have repeatedly demonstrated that definitions of system delimitations can be of immense importance for overall results and conclusions drawn from the study (Villanueva and Wenzel 2007). Although this is also undoubtedly the case in SLCA (Chhipi-Shrestha et al. 2014), little attention has been given to this item as an essential part in the realisation of an SLCA. To the notion of the authors of the present paper, the only extensive discussions on this topic are works by Dreyer and Hauschild (2006), Jørgensen et al. (2008), Parent et al. (2010), Lagarde and Macombe (2012) and Chhipi-Shrestha et al. (2014).

According to Lagarde and Macombe (2012), the concepts used to describe systems and set the boundaries are not very clear in published SLCA literature. Based on the experiences of the authors, many SLCA studies published until 2012 do not clearly explain the conceptual model they have chosen or the criteria on which they have based their choice of boundaries (Lagarde and Macombe 2012). However, the authors do not provide details on how these choices have been handled in published literature. A more detailed observation was realised in 2014 by Chhipi-Shrestha et al. who reviewed 20 case studies and concluded "above all, the cut-off criteria were not specified in most studies". In addition, the amount of SLCA publications has vastly increased since then.

Thus, the overall objective of the present study is to facilitate the future work of SLCA practitioners by providing a critical overview of system delimitation, based on a review of previously published SLCA case studies. Sections 3 and 4 discuss and categorise the different views on the conceptual understanding of the system, how system limits are defined, and how cut-off rules are constructed and implemented. In Section 5, an application-dependent model for system view and cut-offs in different contexts is presented. Finally, Section 6 presents our conclusions.

2 Methodology

This study, adopts the ISO 14040 (ISO 2006a) definition of a system, i.e. "a collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product". Initially, a unit process is defined as defined by the same norm, i.e. "the smallest element considered in the life cycle inventory analysis for which input and output data are quantified", but we will see in Section 3.1 and 3.2 that several SLCA practitioners add an organisational approach to this technical definition. Our study also focuses on cut-off criteria, i.e. the specification of quantity of material or energy flow or the level of social significance "associated with unit processes or product system to be excluded from a study" (ISO 2006a).

In addition, in the present study, the use of the term "product" follows the ISO (2006a and 2006b), i.e. as a product or a service, unless specifically stated otherwise.

This literature review is based mainly on SLCA case studies published in peer-reviewed journals. A literature survey was carried out in international and Brazilian databases (www.sciencedirect.com, www.springer.com and www.periodicos.capes.gov.br) and a web-based search engine (scholar.google.com), using the keywords "SLCA", "Social LCA" and "Social Life Cycle Assessment" in the fields title, abstract and keywords. We also included nine articles addressing life cycle sustainability assessment (LCSA) and several academic reports and books that we judged relevant to the present review. As our objective is to analyse the definition of product system boundaries and the use of cut-off rules in SLCAs, all selected articles include case studies at least partially. Although the review was made with the intention of being comprehensive, studies of relevance might have been excluded. As an example, the increasing mass of SLCA reports commissioned by private entities were excluded, with the effect of the review being focused on the development of the SLCA concept in the academic literature. Privately commissioned studies might differ in various ways in relation to the aspects investigated here, with boundaries potentially being motivated by managerial decision.

This review focuses on case studies following the publication of the Guidelines in 2009 as literature was very limited before their publication (Chhipi-Shrestha et al. 2014) and has been extensively studied (Benoît and Mazijn 2009; Jørgensen et al. 2008). The output is 33 case studies published from 2009 until March 2015. The analysis is realised in a systematised way using double-entry matrices (Tables 1 and 2) with assessment criteria detailed in the next chapters.

After an overview of the conceptual definition of the system presented in reviewed studies, the system units composing the system and data levels used in modelling of the system are identified and discussed. We analyse the different logics that substantiate the construction of the initial system. Afterwards, we identify and categorise the system boundaries used and cut-off criteria as well as how they are justified. Finally, we see how the objective of the SLCA plays a key role in the choice of the conceptual understanding, of the definition of the system and of the applied cut-offs.

3 Conceptual definition of the system

The feasibility of SLCA and the applicability of ISO 14040 (ISO 2006a) was recognised by Weidema (2005), followed by Grießhammer et al. (2006) and the Guidelines. They agree that the ISO norm applies to SLCA, with slight adaptations, should be followed by practitioners. The definition of a product system, its boundaries and cut-off rules are no exceptions. All authors of the reviewed case studies state having followed the above recommendations, by referring to ISO (2006a, b) and/or the Guidelines.

Nevertheless, how they construct their initial system and which elements are comprised within its boundaries vary between authors. We observe differences in the conceptual view they have of a system: what are the smallest elements composing it? At which level are data quantified for those elements? And finally, how were those elements identified?

3.1 The units of the system

In ELCA, unit processes are of a technical and physical nature (ISO 2006a). The initial product system presented in ELCA and the Guidelines is made of chains of technical processes and is usually depicted in a process flow chart, connected through economic and/or physical relations. SLCA literature accepts this definition but also adds different interpretations of the units composing a system and several authors argue that they can be of an organisational nature (e.g. Dreyer et al. 2010a, b; Parent et al. 2010; Lagarde and Macombe 2012).

Defining systems at the organisational level, "from conduct of the company to the social impact" (Jørgensen et al. 2008) is specific to SLCA. Spillemaeckers and Vanhoutte (2004), Dreyer et al. (2006 and 2010a), Macombe et al. (2011) and Zamagni et al. (2011) argue that the social impacts on people in the life cycle of a product have a stronger relation to the behaviour of organisations and companies involved in the product chain than the technical processes themselves. From this perspective, the product system should be composed by the organisations where processes take place.

For clarity, the term "unit" is used in the rest of the article when referring to the smallest part of the system, independently of its nature (technical process or organisational unit). We identify the smallest element of the initial system described in the scope definition stage of the reviewed case studies and if the nature of those units are of technical or organisational. In studies performing ELCA in parallel to the SLCA, the identification of units was restricted to the SLCA. Thirty-one of the 33 studies reviewed (Table 1) describe the initial assessed system as a chain of technical processes or life cycle stages. Amongst them, 9 studies list only life cycle stages and 22 quote technical processes as well, though sometimes not exhaustively. Amongst studies where ELCAs were performed in parallel to SLCAs, technical processes were always quoted.

Paragahawewa et al. (2009) describe a system composed of technical processes but advise to conciliate technical and organisational approaches as both are necessary and add complementary information.

Ultimately, only Dreyer et al. (2010b) and Lagarde and Macombe (2012) do not describe the initial system as a chain of technical processes. Lagarde and Macombe (2012) have an organisational conception, using companies as units of the system initially described. Dreyer et al. (2010b) do not present a specific product system in their article and only mention companies. According to their conceptualisation of the system expressed in a previous article, identifying the technical processes in the life cycle is nevertheless a first stage, while "social LCA must be focused at a higher hierarchical level on the companies in which the processes occur" (Dreyer et al. 2010a).

3.2 Data level

Many authors describe the initial system as a flow of technical processes but obtain useful results by collecting data at a different level. We will see why in the next chapter and how the level of data collection gives another perspective to the conceptual understanding of the system.

Table 1 Summary of observations in the performed review

Reference	LSCA	System boundaries	Data level	Cut-off criteria	LCIA
Albrecht et al. (2013)		Cradle to grave	C/S		Att1
Andrews et al. (2009)		Gate to gate	C/S		Att1
Aparcana and Salhofer (2013)			C/S		Att1
Arcese et al. (2013)			O		Att1
Basurko and Mesbahi (2014)	X		O		Att1
Norris et al. (2012a)		Gate to gate	C/S	SS(AV + SH)	Att1
Norris et al. (2012b)		Gate to gate	C/S	SS(AV + SH)	Att1
Norris et al. (2011)		Gate to gate	C/S	SS(AV + SH)	Att1
Baumann et al. (2013)		Cradle to use	P		Att2
Chang et al. (2012)	X	Cradle to grave	C/S		Att1
Ciroth and Franze (2011)		Cradle to grave	C/S	EL + SS(SH)	Att1
De Luca et al. (2015)		Gate to gate	O	SS(none)	Att1
Dreyer et al. (2010a, 2010b)			O		Att1
Ekener-Petersen and Finnveden (2013)		Cradle to grave	C/S	EL + SS(AV)	Att1
Ekener-Petersen et al. (2014)		Gate to gate	C/S	EL	Att1
Feschet et al. (2012)		Gate to gate	O/P		Csq2
Foolmaun and Ramjeeawon (2013)		Cradle to grave	C/S	IE	Att1
Franze and Ciroth (2011)		Cradle to grave	C/S	EL + SS(SH)	Att1
Hosseinijou et al. (2014)		Cradle to grave	C/S	SS(AV + SH)	Att1
Lagarde and Macombe (2012)		Cradle to grave	O/P	SD	Csq2
Lehmann et al. (2011)		Cradle to grave	O		Att1
Lehmann et al. (2013)	X	Cradle to grave	O	EL	Att1
Luthe et al. (2013)		Cradle to grave	C/S		Att1
Manik et al. (2013)		Gate to gate	C/S		Att1
Martínez-Blanco et al. (2014)	X	Gate to gate	C/S	EL + IE	Att1
Moriizumi et al. (2010)	X	Gate to gate	C/S		Att1
Norris et al. (2014)			C/S		Att1
Paragahawewa et al. (2009)			O	SS(none)	Att1
Ren et al. (2015)	X	Gate to gate	C/S		Att1
Stamford and Azapagic (2012)	X	Cradle to grave	C/S		Att1
Traverso et al. (2012)	X	Cradle to grave	O	EL	Att1
Umair et al. (2015)		Cradle to grave	O		Att1
Vinyes et al. (2013)	X	Cradle to grave	C/S		Att1

Activity variable and SH are types of SSi and therefore presented within brackets

C/S country/sector, *O* organisation, *EL* empirical limitations, *IE* identical elements, *SS* social significance, *AV* activity variable, *SD* significant dependency, *SH* social hotspot, *S/E* stakeholders/experts, *Att1* attributional type 1, *Att2* attributional type 2, *Csq2* consequential type 2 (no consequential type 1 studies identified in reviewed articles), *P* processes

Within reviewed articles, we have identified two of those broader levels of data collection:

– The industrial sector in a given country, region or other defined geographical area, hereafter referred to as "sector/country level"
– The organisation and the surrounding local community, hereafter referred to as "organisation level"

To better apprehend the authors' conceptual definition of the system and analyse how a mapping of technical processes leads to the assessment of social impacts, this study examines at which level data is collected during the inventory phase. As most case studies include different levels of data collection (e.g. national, organisational, process), we focus on the lowest level at which data is available or which is recommended in the study. For example, if data was collected at national,

Table 2 Systematic presentation of linkages observed between case study objectives, conceptual system understanding and the most relevant processes forming the system, used cut-off criteria and main target groups in reviewed studies

Objective of the SLCA	Target group	Social stressor[a]	Cut-off criteria[b]	Relevant data level	Examples
Choice of technologies and suppliers	Designers, internal decision-makers, policy-makers	Processes	The influence of the central company	Organisational	Lehmann et al. (2011)
Product optimization (material choice, etc).	Designers, internal decision-makers, policy-makers	Processes	Activity variables	Country/sector	Ekener-Petersen and Finnveden (2013); Hosseinijou et al. (2014)
Investigate social impacts from a specific sector on macro-basis	Policy-makers	Processes	Hotspots (technical processes)	Country/sector	Ciroth and Franze (2011); Paragahawewa et al. (2009)
Predict impacts of the product's life cycle on an area of protection at the national level or in absolute terms (type 2 assessment)	Designers, internal decision-makers, policy-makers	Processes	Hotspots (technical processes)	Technical process	Baumann et al. (2013); Feschet et al. (2012)
Identify social consequences of projects/investments	Internal decision-makers, policy-makers	Organisations	Actors impacted by the company's future activity (including competitors), identified through the significant dependency model	Organisational	Lagarde and Macombe (2012)
Improve internal performance (changes in the practices of the central company, companies in the value chain) or choose suppliers	Internal decision-makers	Organisations	The influence of the central company	Organisational	Dreyer et al. (2010a, 2010b).
Generation of risk-assessment. Choice of geographical location of an activity or of suppliers within the value chain. External communication.	Clients, NGOs, Internal decision-makers	Processes	Hotspots (sector/ country)	Country/sector	Norris et al. (2012a and 2014)
Identify parts of the system with different characteristics. External communication	Clients, NGOs	Processes	Cut-offs are not made, as the objective is to identify parts of the system with different characteristics (attribute assessment, LCAA).	Country/sector	Andrews et al. (2009)

[a] Determinant factor for what is to be included in the system

[b] The sources of the impacts

sectorial and organisational levels, we will identify the managerial level as being the lowest and will state and analyse only this level in the present review.

In most articles, we could find the apparent paradox mentioned above. Their authors define the technical processes or life cycle stages assessed, though sometimes vaguely, but this information is used to determine which companies operate at those stages or in which countries those stages take place, collecting data at the later levels.

Twenty-one case studies conduct assessments at a sector/country level. The goal of those studies is either assessing the social impacts of a whole sector at a local or national level (e.g. Foolmaun and Ramjeeawon 2013; Hosseinijou et al. 2014), targeting NGOs or policy-makers or conducting a hotspot assessment for a given product category (e.g. Norris et al. 2011, 2012a, b, 2014). We observe that when data is assessed by sector, it is specific to a geographical region. The Guidelines see the use of non-region specific sectorial data as contradictory to the often-stated context-specific nature of SLCA and indeed, according to our reading, this does not occur in any of the reviewed studies. Moreover, nine articles focused on this level recommend gathering data at the company level, recognising that sector/country level of data collection is sufficient for decisions at the policy level, but insufficient for decision support related to a specific product.

Overall, 75 % of the articles collect or advocate for collecting data at the organisation level. In some of those articles, this collecting level is related to the objective of the assessment (Jørgensen et al. 2009), e.g. identify social issues within a company or its managerial practices. A bias towards collecting (or advising to collect) data at the organisation level can also be explained by the impact subcategories recommended by the Guidelines, which mainly assess managerial practices at the organisation level as underlined by Parent et al. (2010).

Data are gathered at the organisation level in 11 articles (Table 1), allowing, e.g. an understanding of the impacts of each supplier in the supply chain or an improvement of internal managerial practices. It is noteworthy that most of those studies use information available for the entire company and not data allocated to a specific technical process. Exceptions are Baumann et al. (2013) and Feschet et al. (2012) who list technical processes and gather quantitative data related to this level by measuring the organisational impacts allocated only to the functional unit and not the entire organisation or country. Even in articles where only parts of companies are assessed, such as Ciroth and Franze (2011) who investigate in which company factory the component is produced, data is collected at the level of that entire factory rather than the sole technical process. Jørgensen et al. (2009) argue that theoretically, only the impacts directly related to the production of the product or its components should be included in the assessed system. According to this *allocation of responsibility*, "specific impacts connected to a production line whose products are not part of the assessed product should not be considered" even when they are located in the same site. Nevertheless, they also show that this allocation is not desirable or is difficult to achieve from the point of view of the potential target groups of performed SLCAs, which actually aim at impacting the organisational level rather than the process level.

3.3 Genesis of the system

One of the main challenges in designing the initial system is to identify which elements lead to social impacts. Authors take different approaches when designing the product system and listing the life cycle and processes comprised. Besides mapping material flows, some studies integrate immaterial flows (financial or administrative services) to the assessment (Ciroth and Franze 2011; Dreyer et al. 2010b; Feschet et al. 2012; Lagarde and Macombe 2012; Norris et al. 2012a, b). Such support services are commonly cut-off in ELCA, potentially based on the assumption that they result in insignificant environmental impacts. System design can also depend on (a) the consequential or attributional approach of the study and (b) whether they use a model aggregating the results of indicators (type 1) or representing causal pathways (type 2). Most of the studies reviewed combine type 1 modelling with an attributional approach. They mainly use or derive SLCA system boundaries from ELCA, a procedure maybe influenced by the anteriority of ELCA and by the robustness of this methodology and that is suggested in the guidelines. There is, however, no consensus on whether and how to derive them and several authors are critical to this approach (Lagarde and Macombe 2012; Kruse et al. 2009).

When both an ELCA and a SLCA are realised, we observe that the environmental assessment is always anterior to the social one. Conducting an ELCA influences SLCA system boundaries as the system created for the ELCA is used as a starting point for the SLCA's system. This was observed in all six studies where an ELCA was also realised. A particular case is the one of LCSAs, where ELCA, life cycle costing (LCC) and SLCA are realised in parallel. The guidelines for LCSA (Valdivia et al. 2013) recommend including "all unit processes relevant for at least one of the techniques" in the initial system described for the entire study (specific cut-offs can be made for each dimension subsequently). We observe that many authors of the reviewed studies started by constructing a system for ELCA and identified which parts are specific to SLCA later on, in the inventory part for SLCA (e.g. Macombe et al. 2010; Chang et al. 2012).

Whether system boundaries are derived from previously defined limits (i.e. in ELCA or LCSA) or not, authors (Benoît and Mazijn 2009; Kruse et al. 2009) agree that a specific refinement must be realised when conducting a SLCA. Thus, a second "layer" must be added when defining the system for a SLCA, as this layer allows practitioners to identify the source of the social stressors, corresponding to the data level (Parent et al. 2010).

The units of this second layer are of an organisational nature, referred to as "context unit" by Parent et al. (2010). These are connected amongst themselves by financial or contractual ties and have the central organisation or country as the focal point. Some authors describe this mapping logic as following a supply chain or a value chain vision (e.g. Dreyer et al. 2010b; Lehmann et al. 2013). The system results in a mapping of organisations related to the central organisation or amongst themselves by financial and/or contractual ties.

The first layer of the system composed of technical processes is also present in the three type 2 SLCAs (Table 1). Two of them (Baumann et al. 2013; Feschet et al. 2012) do not identify the second layer for the entire system they study. Instead, authors directly relate social impacts to processes through pathways varying from one method to the other. This is due to the impact assessment method and the nature of the endpoints used. In both studies, endpoints are related to health and life expectancy (respectively DALY and LEX). Social stressors, i.e. the sources of the impacts, can be organisational, within the central company, its suppliers, the State or national households reacting to the process (Feschet et al. 2012), but they can also be of a technical nature such as the amount of toxic emissions caused or the number of injuries prevented by the process (Baumann et al. 2013), hence not related to a particular managerial practice, region or organisation.

We also observe studies, which, although not stating this explicitly, assess consequences with social relevance associated with possible changes in the life cycle of the investigated product or service, analogously to consequential ELCA modelling (Ekvall and Weidema 2004). In Lagarde and Macombe (2012) and Feschet et al. (2012), the conceptual understanding of the system focuses on unit social impacts from changes that the investigated product chain induces beyond its frontiers, differing in that socio-economic relationships and fluxes, rather than material fluxes, are used to identify the relevant units of the system. For example, Lagarde and Macombe (2012) design the assessed system analysing the relationships between the central firm and the sociosphere. They introduce the concept of the systematic competitive model, merging notions from the strategic arena and the value net. The system they describe encompasses all companies within supply chains that are in direct or indirect competition with the central company or that are complementing it. The system is designed starting from a change occurring in the central firm and envisions the complex relationships existing between companies, such as coopetition (cooperation between competitors). The result is a multidimensional and dynamic network, unlike most SLCA systems, modelled as static chains of processes. Both reviewed studies performed with consequential system modelling use a type 2 LCIA approach. It is however our opinion that there is no relation between consequential modelling and a specific SLCIA approach.

4 Cut-off criteria and system boundaries

In environmental LCAs, after designing the initial, ideal, system, authors often determine narrower boundaries that define which elements will be included in the inventory and the rest of the assessment. They realise cut-offs. Is it the case in SLCAs? What are the cut-off criteria defined and applied in reviewed case studies? What are the implications of those cut-offs?

4.1 Cut-off criteria

Cut-off criteria are the rules and thresholds used to exclude elements from the system initially defined. In an ELCA, cut-off criteria are set in line with goal and scope of the study, determined systematically and quantitatively, in order to lead to unbiased results and comparisons (ILCD 2010). They are used for example to exclude all quantitatively not relevant non-reference product flows, waste flows, and elementary flows.

Cut-off criteria are also necessary in SLCA, as the product chains can be infinite (Macombe et al. 2011). Yet, the Guidelines give limited guidance in relation to cut-off criteria setting. They state that all relevant parts of the life cycle have to be included in the study and that “it is rather a question of motivating the cut-off-criteria”, which could be interpreted as if any cut-off is accepted, as long as the choice is motivated by the goal and scope definition of the study.

Cut-offs made in the assessment of the product system in reviewed case studies were analysed from three perspectives: (i) are cut-offs made, discussed and clearly stated; (ii) what method was used in setting cut-offs and (iii) are they justified, and if so, how.

Fifteen out of 31 case studies defining a system (Table 1) do not clearly state and discuss cut-off criteria used in the definition of the investigated system, i.e. included/excluded processes are not clearly specified and/or choices are not justified.

Out of the six studies deriving system boundaries from ELCA, only De Luca et al. (2015) applied specific cut-off rules for the SLCA. Although the system boundary “was chosen according to parallel studies that were developed using the same data to assess economic and environmental sustainability”, it is also in those phases that “most situations of social concern develop”. Baumann et al. (2013) state that “the system boundaries of the S-LCA are the same as those of the corresponding E-LCA” without further detail. Basing system boundaries on previously performed ELCAs is coherent with recommendations in the Guidelines, stating that the calculation basis shall be as consistent as possible. However, consistent does not mean identical and system definition and cut-offs made in ELCA are based on environmental relevance, which can differ from social relevance (Kruse et al. 2009). As an example, services are typically not included in process-based LCA databases. However, they are included in economic input/output (IO) models and therefore in IO-LCA databases (Benoît and Mazijn 2009). Services may be worker intensive activities, and thus, relevant to include in an SLCA.

Similarly, in six of the nine LCSAs, the scope differs between social and other dimensions of the assessment, but only two of them (Martínez-Blanco et al. 2014 and Lehmann et al. 2013) describe social cut-off criteria.

We identify 15 SLCA case studies presenting cut-off criteria in a qualitative or quantitative way, even briefly. Amongst these, we distinguish four categories of criteria expressed or implied. In some studies, these criteria coexist (Table 1).

4.1.1 Social significance

Following the recommendation of the ISO 14044 (ISO 2006b) to set boundaries by evaluating the "environmental significance" of each process, it is suggested by Grießhammer et al. (2006) and the Guidelines to set the cut-off rule for SLCA based on "social significance". Weidema (2005) states that processes should be excluded from the product system only if this exclusion does not change the final result. Jørgensen et al. (2008) add expert judgement to this list of different methods for defining cut-offs. Those suggested cut-off criteria are basically qualitative, as underlined by Chhipi-Shrestha et al. (2014).

We observe that social significance is referred to in nine case studies and that the methods used to identify it can be qualitative, quantitative or semi-quantitative.

In six cases, it is stated from a qualitative point of view. The SLCA realised by De Luca et al. (2015) for example applies to "the phase in which most situations of social concern develop" and Paragahawewa et al. (2009) "focus on all socially significant impacts from both company and production specific activities".

Six authors take a quantitative approach through the use of activity variables, with the underlying assumption and justification that the processes where more activity takes place will result in more social impacts. Two types of activity variables appear in the articles: work hours and material use. Martínez-Blanco et al. (2014) use work hours to decide which background systems should be included, "the most working time-intensive input". Ekener-Petersen and Finnveden (2013) analyse the relative proportion of material used to produce a laptop, expressed in percentage of the total weight, in order to decide which raw materials will be analysed.

Another method used to evaluate social significance is through social hotspot assessment, which could be seen as semi-quantitative. Social hotspots are "unit processes located in a region where a situation occurs that may be considered a problem, a risk or an opportunity, in relation to a social theme of interest" (Benoît and Mazijn 2009). According to Hosseinijou et al. (2014), they allow analysing the social significance at each life cycle stage. Six case studies conduct a hotspot assessment during scoping (where the existence of hotspots is used as a cut-off criterion) or during the characterisation phase to identify significant issues in the product system. We will review here the hotspot assessment methods these authors developed, even when they were used during the LCIA phase, as they could be used to realise cut-offs as well. All hotspot methods presented contain the two same stages; first activity variables are used to select technical processes for which potential social impacts are then identified. Norris et al. (2011, 2012a, b) developed a method based on data included in the Social Hotspot Database (SHDB). It combines a worker hours model, based on global input/output tables, which makes it possible to identify work intensity in different parts of the supply chain. Modelling of the supply chain is achieved by looking at the worker hours share contributed from country-specific sector (CSS) indicators potentially involved in the supply chain (Norris et al. 2012b). In an SLCA of strawberry yogurt, Norris et al. (2012b) identify that 89 % of the worker hours are within the top 200 CSS for dairy products and assess the risk of each of those CSS. However, authors acknowledge that sectors in the supply chain that did not rank high for worker hours can be of importance and, thus, supplement this method with a literature review. Hosseinijou et al. (2014) propose the use of material flow analysis to identify the main stream of material through its life cycle. Interviews were then performed with experts to identify the processes contributing to most pressing socio-economic issues within identified streams. Some social issues being critical, in the sense of the mere existence being unacceptable, independent of the size, their possible existence could also be a justification for including a unit in the system, the existence or absence of the risk of occurrence being the cut-off rule. We nevertheless did not observe the use of this rule in the reviewed articles.

4.1.2 Empirical limitations

In seven cases, cut-offs were justified through data availability and in one through time availability. Franze and Ciroth (2011) state that "the disposal is disregarded due to lack of reliable data" and that "out of consideration are capital goods for simplification reasons". Martínez-Blanco et al. (2014) state about waste and capital goods, that "these processes include many additional companies […] and would require a great amount of extra social data". A different type of empirical motivation is of methodological nature. Various authors applying the Guidelines methodology, such as Ciroth and Franze (2011), excluded the use phase, as the characterisation method does not allow its assessment.

4.1.3 Identical elements

In comparative SLCAs, identical processes can be cut-off (ISO 14044, ISO 2006b). Identical elements are here understood as the identical technical process located in the same organisation or country (Lehmann et al. 2013; Martínez-Blanco et al. 2014; Chang et al. 2012) or identical lifecycle phases (Martínez-Blanco et al. 2014; Foolmaun and Ramjeeawon 2013). Foolmaun and Ramjeeawon (2013) use this rule to leave outside of the system boundary all processes outside the Mauritanian territory. They compare social impacts of disposal alternatives of used PET bottles. Outside of Mauritius, the life cycles of those alternatives are identical. As a consequence, stages such as shipping or recycling of the PET bottles can be left out. Martínez-Blanco et al. (2014) also chose to assess "only those stages and substages [...] that differ between the alternative fertilizers".

4.1.4 Significant dependency and decision relevancy

Lagarde and Macombe (2012) present the systematic competitive model as a method for developing the initial system and the significant dependency criterion for defining its boundaries. The organisations included within the system boundaries are those whose socially effecting behaviour would "change if the functioning of the life cycle under study changed", which could be compared with consequential modelling thinking.

Though this criterion is not related to the ethical behaviour of the central company, nor its managerial practices, it can be read in conjunction with the approach of Dreyer et al. (2006) in that it relies on the influence of the central company. Dreyer et al. (2006) indeed recommend including only decision-relevant companies, i.e. those that can be influenced by the central company (the company and its tier 1 suppliers). We notice that this criterion was not used in reviewed case studies. It is quoted by Hosseinijou et al. (2014) who dismiss it as it cannot apply to the use phase. Lehmann et al. (2011) argue that the results of the SLCA will have an impact on the first tier suppliers at most but do not enforce this cut-off either in their study.

4.2 Sensitivity analysis

Both ISO 14040 (ISO 2006a) and ILCD (2010) state that made cut-offs should be justified through an iterative process, where the impact of made delimitations is investigated. This is recognised also in the Guidelines, where it is recommended that SLCA studies attempt to characterise the sensitivity of their results due to system boundary decisions. However, unlike in ELCA (Laurent et al. 2014), this is currently very uncommon in SLCA case studies, and only two such assessments were identified amongst reviewed articles. Baumann et al. (2013), whose LCIA method is quantitative, conduct an analysis similar to those realised in ELCA by estimating the impacts of cut-off processes and calculating their effect on the final result. Lagarde and Macombe (2012) assess the pertinence of the method they propose for system modelling by comparing it to using a value chain approach where only organisations with a client-supplier relationship are included in the system. They conclude that, even using the same set of data, results are opposed depending on whether the system was designed with a value chain approach or using a systematic competitive model.

5 An application-dependent approach

It is recognised that differences in approaches in system definition may be explained by differences in their intended use and that width, depth and information needs in SLCA must be balanced according to the goal of the study and the intended audience (Jørgensen et al. 2008; ISO 2006a; Benoît and Mazijn 2009). It seems irrelevant to search for one single and "correct" conception of system view and cut-off criteria. Rather, some context-derived key elements are always necessary to identify relevant approaches to these issues.

Table 2 was created to show application-dependency in SLCA studies. The suggestion presented here is clearly not an exhaustive listing of potential applications and merely takes into account what we observe in the analysed case studies. It also presents our opinion on how the logic used for system definition, boundary setting and data collection can help in achieving the SLCA's goal. The matrix also aims to make clear that, as an SLCA can have various objectives and targeted audiences, several system approaches often coexist in the same assessment, and hence, various layers of cut-offs can be applied in the same study.

Which logic one should use when designing the initial system depends on the objectives and the audience of the assessment. In the case of product optimisation (line 2 in Table 2), a system focusing on the organisations or factories where the processes take place with the product as the focal point will give more visibility on the impacts a modification in the design of the product can have. When the company wants to communicate the social impacts of a product externally (line 7 in Table 2), identifying companies related to the central company by contractual ties can be more appropriate as it allows more transparency. If decision-makers in the central company want to improve the social impacts of their product through its life cycle (line 6 in Table 2), they will be interested in the organisations their company can affect and will gain from mapping a system starting at the central company and following contractual or financial ties. As the level of influence they have on the organisations of the system is critical, the cut-off applied should exclude those organisations that the central company cannot influence (Dreyer et al. 2006). For product comparative assessments, the system genesis can follow any of the stated logics, as long as the same logic is followed for mapping all compared systems, and where all identical processes are cut-off.

It is noteworthy that all studies reviewed do not follow exactly the logic presented in Table 2, sometimes for empirical reasons or because the system definition was not detailed. However, the matrix (Table 2) might advance reflections of the context of the SLCA and result in more transparently described and robust system boundary settings and cut-offs in future work.

For example, assessments aiming at helping designers and internal decision-makers choose amongst various technologies or materials for the production of the central product (line 1 in Table 2) should be able to provide an output showing the impacts of each alternative product or technology on the entire life cycle. The influence a technology has on the system can be more visible by mapping the organisations directly related to the use of this technology. From this perspective, a justified cut-off is the elements that the decision-makers from the central company cannot influence and therefore cannot optimise, as is the case in Lehmann et al. (2011). Another relevant cut-off for this type of system can be quantitative, based on activity variables. It can apply if the central organisation can influence all organisation of the system or if the assessment is generic and directed at policy-makers (e.g. Ekener-Petersen and Finnveden 2013).

6 Conclusions

It has been recognised that the lack of a clear conceptual definition of the system and justified cut-off criteria could discount the robustness of an SLCA. Nevertheless, methods and justifications used in these processes have gained little attention in previous reviews of this research field.

In the reviewed studies, two differing conceptual views were expressed: one defining the system as a group of interconnected organisations and the other representing it as a chain of technical processes. All systems were nevertheless based on a vision of the life cycle in technical terms, similar to ELCA system boundary setting and making up the first layer of the SLCA system. How authors identified social stressors based on technical processes differed between cases.

Two main factors influence how the organisational layer of the system is defined: the SLCIA method used and the objective of the study (and target audience).

In type 1 assessments, the system consists of the organisations where technical processes take place or that are directly or indirectly associated to those processes and related services. These organisations are the sources of social stressors. Most systems defined in type 2 assessments consist of technical processes only and will serve to identify social impacts directly or indirectly related to the processes and the flow of material and energy.

The assessment's data level was used in this review to understand which were the social stressors in the system. Data level is related to the objective of the study, empirical limitations and the SLCIA method chosen but is not a direct consequence nor motivation for system definition.

The review shows that cut-off criteria are rarely detailed. Amongst these, we identify four types of criteria: social significance, empirical limitations, identical elements and significant dependency and decision relevancy. The first of these criteria is assessed through activity variables, identification of hotspots or author's and experts' opinion. Empirical limitations and identical elements are self-explanatory, whereas the other criteria are mainly assessed through author's opinion.

The objective of the study influences the design of the initial system and the logic followed when designing the network of organisations connected to the product's life cycle and cutting off parts of this initial system. It is irrelevant to search for any "correct" conception of system view and cut-off criteria, and relevant approaches to these issues should rather be application derived.

Mainly because most reviewed studies focused on developing SLCIA methodologies, they did not detail system boundary setting in a systematised and robust way. The lack of clear conceptual approaches of the system and the scarcity of boundary setting methods in SLCA hamper knowledge build-up in this area.

A first attempt of systematisation of how this was made in previous works has been presented here; forming a basis for increased reflections on these important parts of the assessment in future SLCAs. We recommend more transparency on choices made in system creation in future SLCA case studies as well as the use of detailed cut-off criteria and the application of sensitivity analyses investigating the influence of made choices. More research is also needed to understand how the organisational layer of the system can be defined based on the technical one, how they relate to the objective of the assessment and how systems will differ depending on the SLCIA method used.

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