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Definition of Product System and Solving Multifunctionality in ISO 14040–14044: Inconsistencies and Proposed Amendments—Toward a More Open and General LCA Framework

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INTRODUCTION

The ISO 14040–14044 standards (ISO, 2006a,b) are a set of key documents for LCA practitioners. In the open and inclusive procedure to form these standards, finding a consensus is important, but obtaining consistency is as well. The latter ought not be relegated to a less important sphere of concern. If "standards ensure consistency of essential features of goods and services," as mentioned by the ISO (2022), they should not have inconsistencies themselves. Therefore, we want to address specific points of inconsistency in the ISO 14040–14044 standards. Yet, we first exemplify what an inconsistency in a standard implies with following simple example. Considering a hypothetical ISO standard on Blu-ray Disc (BD) dimensions, it would be inconsistent to state at one point that a BD should be 2 mm thick and at another point in the standard that the thickness range is 1–1.5 mm. Even if that standard would have been published and approved by the majority of the respective ISO-committee, it would still not be acceptable to have such inconsistency, necessitating correction afterwards. In the case of the example, BD producers would not know whether 1–1.5 or 2 mm is the standard thickness, making a correction to the standard needed. Note that while a certain degree of flexibility might be possible (e.g., a range in BD thickness), the degree of flexibility should be consistently fixed in the standard. In our work, we focus on two aspects of the ISO 14040–14044 standards where particular inconsistencies are persistent: (1) the definition of a product system and (2) multifunctionality solutions. Although amendments of the respective standards have been introduced (ISO, 2020), these inconsistencies remain. In the first section of this article, we explain these aspects and elaborate on the inconsistencies, which have already been brought forward in literature. In the second section, we propose possible amendments to resolve them. One specific proposed amendment is a more open and general LCA framework with a novel definition for product system, which will be explained in detail further on. In the discussion section, we conclude matters and provide practical guidance.

INCONSISTENCIES CONCERNING PRODUCT SYSTEM AND MULTIFUNCTIONALITY SOLUTIONS

The two prominent inconsistencies with the current ISO standards are discussed in detail below. The elaboration on each inconsistency consists of specifying (a) what is written in the standards, (b) the description and explanation of the inconsistency and (c) the implications for LCA practice and interpretation.

(1) Definition of product system:

(a) *What is written in the standards?*

The purpose of an LCA is to assess the environmental impacts of a product system (ISO, 2006a,b). In the main text of the ISO 14040 standard, a product system is 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." It thus entails a product life cycle, which is defined in the latest amendment (ISO, 2020) as "consecutive and interlinked stages, from raw material acquisition or generation from natural resources to final disposal." The fact that it is a life cycle of a "product" and that it encompasses consecutive and interlinked stages, delimits the focus on the actual life cycle stages of the particular product. Yet, in the Annex A of ISO 14040 is mentioned that: "the products and processes studied in an LCA are those affected by the decision that the LCA intends to support."

(b) *Description and explanation of the inconsistency*

The statement in the main text and the one in Annex A are contradictory, as a product system cannot be both a consequence of a decision and a product life cycle, as highlighted by Schaubroeck et al. (2021b). For example, if we take a product off the shelf in a shop, the product life cycle includes the interlinked past production of that product, prior to it ending up on the shelf. However, the consequences of the decision to purchase the product will only cover the effects subsequently caused by that purchase, and thus exclude the production of that particular finished product. Hence, these approaches lead to different product systems. Note that a decision to purchase may, among else, induce a possible production of others and also similar goods by the market in the future. This induced production of similar goods is probable but differs from the production in the past. This difference also pertains to background processes such as the difference between the actual electricity suppliers for the production in the past and the ones affected by the decision in the future. Overall, the definition of product system in the main text does not align with the definition of Annex A because the former definition implies that the product system (1) includes certain processes that are not affected by the decision (2) and excludes certain processes that are affected by the decision. For a more thorough explanation, please see the work of Schaubroeck et al. (2021b).

The first definition, i.e., considering a full product life cycle, as stated in the main text of the ISO standard, is at the core of the attributional LCA (ALCA) approach. The other approach, concerning consequences of a decision as stated in Annex A, aligns with consequential LCA (CLCA) (UNEP-SETAC, 2011; Schaubroeck et al., 2021b). These two contradictory product system definitions in the ISO standard can hence be related to the difference in ALCA and CLCA. Studies have showcased the considerably different outcomes that can be obtained between ALCA or CLCA for the same studied product (Wardenaar et al., 2012; Weidema, 2017; Heimersson et al., 2019; Schaubroeck et al., 2021a). In the context of ISO 14040–14044, the inconsistency of the product system definition in general and the need for a differentiation between attributional and consequential thinking has already been highlighted by Weidema (2014), although the definitions presented in latter article are not in line with UNEP-SETAC (2011) definitions, and are presented without reference and without consensus. Overall, the consideration of these two LCA types (ALCA and CLCA), strongly relates to the contradictory product system definitions in the ISO standards, but the latter inconsistency is still there even without specifying ALCA and CLCA in the standard. Note that, while the product system as defined in the main ISO text and ALCA, is not the collection of affected processes or consequences of a decision, such a product system and ALCA still can support a decision in another way, but such an elaboration is outside of the scope of this article.

(c) *Implications for LCA practice and interpretation*

Finally, this inconsistency implies that the practitioner is provided with two contradictory and inconsistent options to construct and interpret a product system, leading to different and inconsistent results and messages.

(2) Addressing multifunctionality:

A widely recognized and debated challenge in LCA is how to best handle multifunctionality. This issue concerns processes or systems providing multiple products, here called co-products, that have different functions, and the assignment of impact to these products. See the work of Guinée et al. (2021) for a more thorough elaboration of multifunctionality. In **Table 1**, we present an overview of certain multifunctionality solution types (partitioning, system expansion, substitution, etc.) as discussed in this work.

(a) *What is written in the standards?*

For the multifunctionality issue, the ISO standards present a fixed hierarchy of a limited set of solutions. This is elaborated in section 4.3.4.2 of ISO 14044, where is also written: "The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below." We refer to the standards, and the amendment (ISO, 2020), themselves for a consideration of the respective steps, i.e., the solution hierarchy, in detail. However, the respective ISO standard also states that the first phase of the LCA method is the specification of a goal and scope, on which further methodological choices should be based. Specifically in ISO 14044 is mentioned that: "LCA studies shall include the goal and scope definition" and "In defining the goal of an LCA, the following items shall be unambiguously stated:- the intended application;- the reasons for carrying out the study [...]." This should be regarded

TABLE 1 | A specification of the product system and types of multifunctionality solutions in line with the goals of a more open and general LCA, attributional or consequential thinking. For the latter two, we build further on recently published works (Schaubroeck et al., 2021a,b).

	More open and general LCA	**Attributional LCA (ALCA)**	**Consequential LCA (CLCA)**
Product system	The product system comprises all processes interrelated with the object of study as specified in the goal.	"The system analyzed ideally contains processes that are actually directly linked by (physical[a], energy, and service[b]) flows to the unit process that supplies the functional unit or reference flow" "In theory, if one were to conduct attributional LCAs of all final products, one would end up with the total observed environmental burdens worldwide" (UNEP-SETAC, 2011)	"In theory, the systems analyzed in these LCAs are made up only of processes that are actually affected by the decision, that is, that change their output due to a signal they receive from a cause-and-effect chain whose origin is a particular decision" (UNEP-SETAC, 2011)
Multifunctionality solution types	*(if possible and to avoid the issue, apply* ***Subdivision****, in the sense of a further specification of subprocesses per co-product, as a general way of avoiding the issue.)*		
	A general alternative solution is **System expansion** (which we advise to rename as **Functional unit expansion):** comprising an expansion of the functional unit to represent all co-products, and thus presenting the impacts of all of them together. It deviates from a focus on single products and could be used to evaluate a process or an entire system (Schrijvers et al., 2020).		
	The multifunctionality solution should be in line with the goal of the study.	**Partitioning*:** splitting the inputs and outputs of processes/systems as such among co-products based on a certain key or rule (e.g., based on the economic or physical attributes of the co-products or physical relationships)	**Co-product effects,** which cover the extra effect of the co-products, of which the substitution/ "avoided burden" effect is just one example. Another example is product benefit consideration (Schaubroeck and Rugani, 2017; Schaubroeck and Benetto, 2018).
		The approach is artificial and selection of a specific partitioning key will therefore always remain partially subjective, but can be linked with a certain goal.	The approach aims to reflect reality and is a modeling effort, pertaining to certain modeling parameters (e.g., demand constraint for substitution).

ALCA and CLCA are just two types of the more open and general LCA framework on which we focus here. More types may exist or may be conceived.
**Concerning cut-off as a solution for multifunctionality, Schaubroeck et al. (2021a) mentioned "cut-off" as a solution type for multifunctionality in case of ALCA. This is indeed the case in practice since it has been applied, notably for cutting of irrelevant or negligible flows, but theoretically it goes against product system definitions (Schrijvers et al., 2020). Even more, a cut-off might be seen as needed to obtain concrete results in case of infinite amounts (Schaubroeck et al., 2021b).*

within the general goal of LCA to evaluate the environmental impact of a product system. Further text parts specify the need for the scope to be in line with this goal: "The scope, including system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA." Concerning what the scope entails, it is written that: "In defining the scope of an LCA, the following items shall be considered and clearly described: […]-allocation procedures […]" (multifunctionality solutions concern allocation procedures). Hence, multifunctionality solutions should be in line with the defined goal. Other statements in the standard also reiterate this dependency of the conducted LCA on the goal and scope, e.g., "Data selected for an LCA depend on the goal and scope of the study."

(b) *Description and explanation of the inconsistency*

The inconsistency is that the limited hierarchy for solutions for multifunctionality, does not consistently allow making methodological choices that align with a certain goal, nor is the hierarchy based on a clearly articulated logic (except for subdivision but this implies revising whether a multifunctionality problem exists at all in the first place). This issue has similarly been brought forward in the literature (Pelletier et al., 2014; Moretti et al., 2020; Schrijvers et al., 2020). How to address multifunctionality is closely related to the goal of the study and the definition of product system, since certain multifunctionality solution types uniquely pertain to either ALCA or CLCA (See **Table 1**). For example, several researchers have pointed out that, as a multifunctionality solution type, partitioning should be among else used for ALCA and not CLCA, while substitution among else for CLCA and not ALCA (Pelletier et al., 2014; Schrijvers et al., 2020). Substitution has also been explicitly introduced in the second ISO 14044 amendment (ISO, 2020), but without specifying the goal-dependency of its application. Furthermore, there is also the distinction between "system expansion" and substitution, also called "avoided burden," which is of concern. Although the recent second amendment of ISO 14044 presents them as identical, the ambiguity and loss of the original concept of system expansion has been pointed out by several authors (Schrijvers et al., 2020; Heijungs et al., 2021; Schaubroeck et al., 2021b), suggesting the need to consider them separately, given that they are goal-dependent. Because co-products are considered as well as the substitution effect, substitution has been named "system expansion + substitution" by some (e.g., Pelletier et al., 2014). We stick to just naming it "substitution," and it should be considered separately from the original concept of system expansion. Alternatively, perhaps calling the original concept of system expansion, "functional unit expansion" would be more appropriate and less confusing, which we advise in this work. However, such a name change needs to be agreed upon. See **Table 1** for an overview. Coming back to the inconsistency at hand, despite the goal dependency of all these multifunctionality solutions, in the hierarchy

of both the original and amended ISO 14044, there is no specification of a solution choice based on the goal.

Moreover, when focusing on partitioning, the choice for a certain partitioning key is to a certain degree fixed in the ISO hierarchy. According to the second step of the hierarchy in ISO 14044, partitioning should be based on physical relationships, i.e., applying a physical partitioning key. This should have priority over partitioning based on other relationships, e.g., economic partitioning keys, specified in the third step. This is further specified in the amendment text (ISO, 2020), but a prioritization of a physical partitioning key in certain cases still pertains. Yet, partitioning (e.g., used in ALCA) is always partially subjective (Pelletier et al., 2014; Schrijvers et al., 2020, 2021), as partitioning is an abstraction of reality, i.e., partial processes are abstract constructs (Schaubroeck et al., 2021b). Rational reasons cannot absolutely define but only support and guide this choice. Logic cannot unequivocally serve as the basis for selecting a physical partitioning key over an economic one. Hence, the choice of partitioning key is value-laden and goal-dependent, and is a choice best made by or in the interest of the users of LCA results, such as NGOs, industrial stakeholders and policymakers. Letting a limited group of scientists and industrial actors, such as those participating in the development of ISO standards, pre-define such subjective choices limits the applicability of the standardized LCA methodology and goal, to only the perspectives represented by this group, whereas in phase 1 of the LCA methodology the goal is kept more open.

Overall, prioritizing or imposing multifunctionality solutions in contradiction with or regardless of the specifics of the selected goal, to be defined in the first phase of LCA, is inconsistent with the general goal-and-scope-dependency of methodological choices, as also brought forward in the standards.

(c) *Implications for LCA practice and interpretation*

This inconsistency in the ISO standards, implies that for a practitioner it is unclear whether to select a certain multifunctionality solution in line with the foreseen goal or according to the hierarchy, which is possibly not in line with a foreseen goal. This all leads to inconsistent and possibly non-sensical outcomes and messages.

In this paragraph, we will shortly conclude on these inconsistencies and highlight their manifestation. Most notably, inconsistencies and/or lack of clarity concerning the aspects of product system definition and multifunctionality, similar to those present in the ISO standards and possibly originating from them, can also be found in LCA guidance documents, LCI databases and case studies. For example, many studies still apply partitioning to address multifunctionality problems at the level of production processes (following attributional thinking) in combination with the substitution approach for the multifunctionality of waste valorization (following consequential thinking), which is inconsistent if the aim is to conduct either ALCA or CLCA (Schrijvers et al., 2016; Heimersson et al., 2019; Schaubroeck et al., 2021a). Such a combination addresses an unclear and commonly not specified research question, in between consequential and attributional thinking. However, the more unspecific the research question, the less it is in line with the need for specification in the first phase (goal and scope) of the LCA methodology, as brought forward in the ISO 14040–14044 standards, and the more the relevance of the study is unclear and questionable. Overall, the LCA community and users of information from LCA studies would clearly benefit from increased clarity and consistency with respect to these two aspects.

PROPOSAL FOR POSSIBLE AMENDMENTS

In this section we present specific possible amendments to resolve these two inconsistencies.

Definition of Product System

A first solution is to delete the statement in Annex A of ISO 14040, which would imply the standard to be close to ALCA as defined by UNEP-SETAC (2011). A second alternative is to change the respective Annex A statement. This could for example be changed into a statement that specifies how ALCA can support a decision differently. This all would then require that the whole Annex A.2 also be revised in its aim. As a third solution, the definition of product system could be adapted, e.g., specifying a product system in general, as shown in the respective column in **Table 1**. This is, in fact, a novel product system definition that is valid for both ALCA and CLCA. In case of CLCA, it would cover all proceeding processes after a decision (the object of study) based on a consequential propagation (the way the processes are interrelated). In case of ALCA, it would cover all proceeding and preceding processes of a product-providing process (object of study) based on interlinkage through physical, energy and service flows (the way the processes are interrelated). This novel product system definition is also open to any possible other and potentially new, types.

Addressing Multifunctionality

Multifunctionality solutions should be selected in correspondence with the goal and scope definition, meaning that the respective ISO standards should either (a) avoid mentioning solutions or (b) just present types (as done in **Table 1**) or examples, in line with certain goals, without defining a prescribed hierarchy.

OVERARCHING AMENDMENT IN FOCUS OF THE STANDARDS

As these two inconsistencies are intertwined and relate with the focus of the ISO 14040–14044 standards, we shortly propose two encompassing/overarching alternatives with a consistent focus. Other alternative foci may exist or may be developed but are not listed here. Our considered two alternatives might necessitate other changes than only those concerning product system definition and multifunctionality solutions, but this is out of scope for this article.

Consider a More Open and General LCA Standard

Considering that there are multiple LCA methods (to which ALCA and CLCA belong), the ISO 14040–14044 standards could be amended to represent a more open and general LCA framework. The product system definition and multifunctionality solutions could then be specified as in the respective column in **Table 1**. Subsections could be added or further additional standards could be developed that represent LCA types (e.g., ALCA and CLCA) with more specificity.

Limit the Standards to a Certain LCA Type and Develop New Standards for Others

The focus of the ISO 14040–14044 could be limited to a certain type, e.g. ALCA, delimiting product system definition and multifunctionality solutions as presented in the respective column in **Table 1**. If the latter exemplary solution were adopted, given the uptake of CLCA and the interest in consequential environmental impact for decision-support, as an alternative, it would be fitting to then also develop a corresponding standard for CLCA.

DISCUSSION

The inconsistencies discussed here concerning the multifunctionality solutions and product system definition in the ISO 14040–14044 standards should not be ignored. We think the ISO committee should address these inconsistencies as quickly as possible. We present several possibilities as to how to deal with them, but it is up to the committee to select one or perhaps conceive others. In the meantime, we recommend in the context of LCA to not consider the current ISO hierarchy concerning multifunctionality (but align it with the goal selected, e.g., see **Table 1**), and consider that a product system can be either a product life cycle (ALCA) or the consequence of a decision (CLCA). In other words, a more open and general LCA framework, as presented in **Table 1**, is ad interim advised, in our opinion. This framework better aligns with a more divers "good practice," making it perhaps the best option in the long run. Furthermore, the open nature of our proposed LCA framework may be considered acceptable as the respective ISO standards are already open to a certain degree (Baitz et al., 2013). As a final message to the practitioner, keep also in mind that in no way should a standard impede research progress in the sense of not permitting altered or new concept developments related to LCA. Rather, be explicit about any such deviations (only advised if very minor), name the concept differently or present a compelling case for a change in the ISO LCA standards.

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TS wrote the original draft preparation. TS, DS, SS, CM, AZ, NP, GH, and MB further improved, corrected, and edited the text. All authors contributed to the article and approved the submitted version.

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