Six areas of methodological debate on attributional life cycle assessment

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Abstract. There is a general agreement in the LCA community that there are two types of LCAs: attributional and consequential. There have been numerous discussions about the pros and cons of the two approaches and on differences in methodology, in particular about methods that can be used in consequential LCA. There are, however, methodological aspects of attributional LCA and how it can be used that need further attention. This article discusses six areas of debate and potential misunderstandings concerning attributional LCA. These are: 1) LCA results of all the products in the world should add up to the total environmental impact of the world, sometimes referred to as the 100 % rule. 2) Attributional LCA is less relevant than consequential LCA. 3) System expansion, and/or substitution, cannot be used in attributional LCA. 4) Attributional LCA leads to more truncation errors than consequential LCA does. 5) There is a clear connection between the goal and questions of an LCA and the choice of attributional or consequential LCA. 6) There is a clear boundary between attributional and consequential LCA. In the article, these statements are discussed, and it is argued that they are either misunderstandings or sometimes incorrect.

1 Introduction

There is a general agreement in the Life Cycle Assessment (LCA) community that there are two types of LCAs: attributional (ALCA) and consequential (CLCA) [1], although the terminology has been slightly different throughout the years. There are different definitions of ALCA and CLCA in the literature, but in most cases there is a general agreement on the

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main principles. Here, ALCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems [2], and CLCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions [3].

There have been numerous discussions about the pros and cons of the two approaches and on differences in methodology [4, 5]. The focus has often been on CLCA, e.g. [6-8]. In the literature, there have been statements about ALCA (e.g. [4, 9]) that deserve further attention. The aim of this paper is to discuss six areas of debate about ALCA and to contribute to the methodological discussion on ALCA and LCA in general.

2 Six areas for discussion

2.1 The 100 % rule

It is often suggested that if one would add up all the ALCAs of all the products in the world, it should add up to the total environmental impact in the world [9]. This is sometimes referred to as “the 100 % rule”.

The 100 % rule interpreted in this way, however, does not seem to be correct, which can be illustrated by a simple example. One could do an ALCA of diesel fuel. One would then include the production of the fuel and the use of it. One could also do an ALCA of a truck. One would then again include the production and use of the fuel. One could also do an ALCA of a waste management system and if that system would include a diesel truck, one would again include the production and use of the fuel. Additionally, different allocation methods applied by different ALCA practitioners to the multifunctional refinery process co-producing diesel among 10-15 other refinery products, could result in another breach of this 100% rule.

This first simple example shows that the production and use of the diesel fuel would be included in many ALCAs, and thus the sum of all ALCAs would be much larger than the total environmental impact of the world. The second example can lead to over- or underestimates. The 100 % rule is thus not correct if defined as above. It could, in principle, be correct if there were rules on which products could be included, e.g., only certain types of consumer end products, the system boundaries for the assessment, which allocation methods to apply, and how to deal with long-living products. One example of this could be when the 100 % rule is explicitly only for “final products” where “final products” are defined “as a product that is directly consumed by humans and not used in the life cycle of another product” [4]. Interpreted in this way, the 100 % rule is only relevant for “final products” and not necessarily for other types of products. In practice, it may turn out to be difficult to identify final products based on this definition. An LCA practitioner is free to choose the product under study, and most LCAs are not of final products, making the 100 % rule less relevant. Another example where the 100 % rule could be valid is for a company that may want to define a 100 % rule to account for ALCAs of all products that they sell and make sure that the sum amounts to the total impact of the company. In this case, they have defined which products to study, and they can define rules for system boundaries, allocation, etc. so that the 100 % rule can be valid. This is, however, a special case and not a general aspect of ALCA.

2.2 The relevance of ALCA

It has been suggested that the sole reason to perform LCA is to use it to support decision making, and that the key requirement for that purpose is that LCA should reflect the environmental consequences caused by the decision, and therefore only CLCA would be relevant, c.f. [10].

This is, however, a simplified view. There are many other uses for LCA apart from using it as a basis for a decision, e.g. learning [11] and finding out which life cycle phase or which product in a consumption pattern contributes most [12]. In these cases, ALCA may be very relevant. Also, much of the arguments against ALCA are based on the assumption that consequentialism is the only appropriate basis for decision-making [13]. However, there may be other relevant bases, e.g. to choose the product with the lowest environmental impacts, which also can be valid [14] and which would instead suggest an ALCA. Therefore, ALCA can also be an appropriate method in many applications.

2.3 System expansion and substitution

A classic problem in LCA is how to handle situations where a process includes several functions, e.g. [1, 2, 4, 9, 15]. An example may be a waste treatment process, e.g. waste incineration, which as one function treats the waste but as a second function also produces electricity. This process can be difficult to compare with a process that only takes care of the waste, but does not produce electricity. This situation can be solved in different ways, and here three approaches will be discussed, c.f. [4]. The first is to allocate (also called partition) between the two functions taking care of the waste and producing electricity. This can be done employing several different methods for the allocation, e.g. [1, 2]. When that has been done, the waste treatment part of the first system can be compared with the second system. A second approach is to conduct a so-called "system expansion" and include two functions: taking care of waste and producing electricity. The process that only takes care of the waste must then be complemented with a process that only produces electricity. The two alternatives are now possible to compare since they fulfil the same functions. A third approach is to credit or subtract the process that only produces electricity from the process that takes care of both the waste and produces electricity. The two systems can now be compared since the first system only has one functional unit, i.e. taking care of the waste. This third option is sometimes called "substitution" or the "avoided burdens" approach [4], but often, the term "system expansion" is used in a broad sense to cover also substitution, e.g. [16, 17], which, however, is debatable [18].

The ISO standard for LCA [19] includes a hierarchy for handling multifunctional processes where system expansion (often interpreted in a broad sense [17, 20]) is presented as a first step to avoid allocation, i.e. before performing different forms of allocation. The ISO standard does not differentiate between ALCA and CLCA. System expansion (in the broad sense) is often used and has, for example, become the dominating approach in waste management LCAs [21]. For comparative studies, system expansion in the narrow sense and substitution gives qualitatively the same result, although the specific numbers will be different [22]. However, this is not the case for non-comparative stand-alone LCAs [23].

It is often claimed that system expansion in a broad sense should not be used for ALCA, e.g. [9]. Others would suggest that system expansion, in a narrow sense, can be used for ALCA, but substitution should not be used [4].

It seems strange not to accept system expansion in the narrow sense in ALCA since a functional unit can cover several functions, c.f. [4]. Unless restrictions on the possibilities of choosing the functional unit are introduced, it seems clear that system expansion in the narrow sense should be compatible with ALCA.

One suggested reason for not accepting substitution in ALCA is that it would be in conflict with the 100 % rule [4]. However, as suggested in section 2.1, if the 100 % rule is not valid, then this argument would not be relevant. Since the results for comparative studies are qualitatively the same for system expansion in a narrow sense and substitution, and they include the same components, it also seems reasonable to also accept substitution in ALCA when substitution in the narrow sense is accepted. System expansion in the narrow sense may be preferable over substitution for increased transparency [22], especially for stand-alone studies. It can also be noted that the data used when substitution is used would probably be different in ALCA and CLCA [2, 24], with e.g. average data being used for substitutions in ALCAs and marginal data for substitutions in CLCAs. It should also be noted that in the special cases where the 100 % rule could be valid, as discussed in section 2.1, then substitution could be in conflict with this rule.

2.4 Truncation and aggregation errors

When conducting an LCA, it is difficult to include all relevant processes, which can lead to truncation errors [25]. It can be argued that this will be a greater problem for ALCA than CLCA since the latter, in theory, only needs to include processes that are changing due to the decision [6].

It may, however, be the other way around, that this is a larger problem for CLCA. One reason for this is related to difficulties in predicting the future and the consequences of decisions [26]. Furthermore, data for consequential assessments are not widely available, and the assessment may require a more comprehensive understanding of the changes to other systems. Another reason is that Input-Output Analysis (IOA) and Environmentally Extended Input-Output Analysis (EEIOA) can be used for providing missing data [27]. This is useful since IOA/EEIOA covers the whole economy of a country and thus does not include the same type of truncation errors as process-based LCA. IOA is by its nature, an accounting tool and therefore more easily applicable in an ALCA context. However, the use of IOA may lead to more aggregation errors since the product groups are broadly defined [28]. Overall, there are different types of calculation errors for both ALCA and CLCA and it is not possible to make a general conclusion on which type may have the largest errors.

2.5 The connection between goal and scope and choice of methodology

It is sometimes expected that there should be a clear connection between the goal of an LCA on the one hand and the choice between ALCA and CLCA on the other. There have been projects where the aim has been to establish this connection. In practice, however, this is not easy to reach consensus on, e.g. [29]. For example, whereas some would argue that LCAs done for different types of environmental labelling are typical ALCA applications, others would argue that since environmental labelling is intended to support decisions, and decision-support should be based on consequences of the decisions, this is instead a typical CLCA application. However, the type of decision is rarely addressed, e.g. consumer, company-level, or political. It, therefore, seems more difficult than expected to establish clear connections between goals of LCAs and the choice between ALCA and CLCA and reach a consensus around these.

2.6 The boundary between ALCA and CLCA

The literature typically suggests two distinctive methodological differences between ALCA and CLCA: 1) The way to handle multifunctional processes where it is sometimes suggested that ALCA should use allocation and CLCA system expansion in a broad sense, e.g. [9], and 2) The choice of data where it is typically suggested that ALCA should use average data and CLCA should use marginal data, e.g. [2, 9]. Sometimes it has also been suggested that the scale of the decision should influence the choice, c.f. [4, 29].

As discussed above, it seems reasonable that system expansion and substitution can be compatible with ALCA. It has also been suggested that there is no strict delimitation of average data for ALCA and marginal for CLCA [4]. Additionaly, based on common definitions of ALCA and CLCA, the scale of the decisions should not influence the choice [4]. Furthermore, in practice, there are a number of studies in between ALCA and CLCA [30, 31] and beyond both [32]. As such, the distinctions are sometimes ambiguous and have not added to the clarity on the differences between the approaches. Therefore, the difference between ALCA and CLCA may be less clear than what is often assumed, and ALCA and CLCA may not be the only two modes of LCA. On the other hand, the possibility of a difference in computational set-up has hardly been addressed [33].

3 Final reflections

When the difference between ALCA and CLCA became established in the LCA community at the end of the 1990s, it was for many somewhat of a revelation. It seemed that many of the classical methodological discussions related to the choice of data, system boundaries, and allocation could now be resolved by making a connection to the goal of the study. In practice, this has turned out to be more difficult than what was expected and discussions are still ongoing. This paper suggests that the differences between ALCA and CLCA are not so clear-cut, neither in theory nor in practice, and that many of the claims of the two methods may need to be revisited. This may require that also some of the basic definitions and methodological aspects of LCA in general and different versions of it be revisited.

More specifically, this paper suggests that the 100 % rule, stating that if one would do an ALCA of all the products in the world, the sum would be the total environmental impacts of the world, is not correct. Also, this paper suggests that system expansion and substitution can be used in both CLCA and ALCA studies.

The discussions here have focused on Environmental LCA, but are equally valid for broader Life Cycle Sustainability Assessments. It is also of relevance for other sustainability assessment tools where the distinction between attributional and consequential assessments may be relevant. We mention in particular IOA and EEIOA, which have been constructed – implicitly – as attributional models and are – tacitly – used to answer consequential questions [34].

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