The common understanding of simplification approaches in published LCA studies—a review and mapping

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Abstract

Purpose This paper aims to investigate the common understanding of the variety of simplifications in LCA, by reviewing what simplification approaches are described in LCA and propose how these simplifications can be categorised. Such an overview can give guidance to researchers/practitioners as to how they should document simplifications and explain their implications to decision-makers.

Methods The basis for this study is a systematic literature review of simplification approaches in LCA, including both previously published overviews of categories of LCA simplification approaches and LCA case studies using different simplification approaches. The PRISMA statement protocol (Moher et al. 2009) was used to minimise the risk of bias, increase scientific validity and provide guidelines for conducting the review.

Results and discussion In all, ten categories of simplification were identified in the literature. Initially, six simplification approaches were identified based on previous categories. However, not all approaches found in case studies fit into these six previously published categories; these were therefore examined and grouped with regard to what was simplified and how, and four additional categories were identified.

The identified simplification categories were mapped and explained in terms of their role in the different stages of the LCA framework. Our results support the idea that simplifications in LCA are most often motivated by a lack of data. Most simplifications target the inventory analysis step, with an aim to reduce the inventory analysis effort.

Conclusions and recommendations There is a need for a common simplification terminology and reporting standard. As this study shows, the categories of simplification from early studies remain relevant despite the development in LCA over the years, but additional categories are needed to cover the different types of simplification being applied in LCAs. What this study also highlights is despite recommendations that have been around for decades, there is still a lack of clear documentation of simplification with consistent terminology. One way, to ensure more transparent documentation of simplified studies and to improve the ability to interpret them and compare results, could be to include the development of a communication standard, with clear terminology as well as investigation of the applicability of different simplification approaches for different product systems and application areas. Due to the wide variety of purposes, scenarios and products assessed, it is impossible to devise a one-size-fits-all approach for simplifications. LCA practitioners need to describe, explain and evaluate the simplifications used.

Keywords Life cycle assessment · LCA · LCA methodology · Simplification · Screening · Streamlining · Literature review

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1 Introduction

The use of life cycle assessment (LCA) in research, industry and policymaking is steadily increasing, as can be seen, for example, in the annual increase in scientific LCA publications (McManus and Taylor 2015) and an observed increase in the number of published LCA-based environmental product declarations in the industry (Toniole et al. 2019). LCA results are typically complex to interpret and require a thorough understanding of underlying assumptions. When LCA is used as a tool to inform decision-making, it is crucial that aspects such as methodological choices, system boundaries, data quality and other delimitations and limitations are transparent and unambiguously communicated. Significant efforts have been made through standards and guidelines (European Commission 2010; ISO 2006a) to harmonise methodology and terminology. Where standards and guidelines do not (yet) provide complete clarification of essential concepts, efforts are still ongoing to clarify methodology. Examples are terminology and frameworks for the handling of data gaps and representativeness (Henriksen et al. 2019, 2018), managing LCA from a sustainability perspective (Guinée et al. 2011) and temporal factors (Collet et al. 2014). The more transparently methodological choices are described with a precise and consistent terminology, the more likely it is that misinterpretation and (unintentional) misuse of results can be avoided.

In the early days of LCA development, how to simplify the methodology received a lot of attention. The need to simplify study results in order to support decision-making was identified, e.g. by Overcash (1994), who reviewed European progress in LCI and LCA methodology. As explained in the LCA ISO standard, the data inventory in LCA involves the “compilation and quantification of inputs and outputs for a product throughout its life cycle” (ISO 2006a) which is usually a very resource-demanding task. Although the ISO standard clearly leaves simplification out of its scope, the level of detail of a full LCA (i.e. one that covers the full scope of the product/service life cycle) is said to “depend on the subject and the intended use of the study”. This implies that “the depth and the breadth of LCA can differ considerably depending on the goal” (ibid.). Indeed, Svensson and Ekvall (1995) noted early on that all LCA studies are simplified at some level, and Graedel (1998) questioned whether a complete, quantitative LCA would ever be accomplished. Around that time, Curran and Young (1996) highlighted the need for a simplified LCA approach that retains the comprehensive nature of the life cycle concept yet allows for more straightforward and rapid yet still accurate evaluations, describing simplification as points along a continuum

between a full LCA and studies that are no longer LCA. However, simplifications are not a continuum with more or less simplification of one kind. The collection and variety of different approaches that are all called ‘simplification’ are significant.

While simplifications should be done in line with and motivated by the question at hand and the intended application of results, it is not unlikely that simplification is often done because of constraints in time, resources, and data availability. According to the ILCD Handbook (European Commission 2010), all cut-offs of the inventory are entirely acceptable and have no consequences on the validity of the LCA, if the extent of the incompleteness is set in line with the goal and scope of the study. As argued by Curran and Young (1996), the selection of a simplified LCA approach should be based on the intended use of results. However, in order to be able to judge whether this is the case, it is central to account for, explain and evaluate the applied simplifications. Contrary to related aspects such as representativeness and data quality, which are well covered by the ISO standard and ILCD guidelines, very little is said about simplifications. With no common terminology concerning simplifications in LCA, there appears to be significant inconsistency in the use of terms like simplified, screening and streamlined when explaining the scope of LCA studies, as observed by e.g. Hung et al. (2018) and Moberg et al. (2014). The lack of common terminology of simplifications may be one reason that simplifications are not well documented in LCA case studies and are therefore at risk of being disregarded and passing unnoticed. This was also noted by Hung et al. (2018), who criticised the haphazard application and observed the risk of undermining confidence in simplified LCA.

In a literature investigation of simplification approaches used in LCA studies, Arzoumanidis et al. (2013) used five scientific databases and citation indexes. However, the search strings used were restricted and did not include LCI, plural forms or alternative terms for LCA such as ‘life cycle analysis’. The review only identified 41 documents, but the main findings are interesting. Additional recent surveys of simplified LCA approaches by e.g. Arzoumanidis et al. (2017); Mendecka and Lombardi (2019); and Soust-Verdaguer et al. (2017) focus on simplification approaches in a specific area of application such as agriculture, wind turbines and livestock. There does not seem to be any previous systematic literature reviews that investigated general LCA simplification approaches.

The aim of this paper is to investigate the common understanding of the variety of simplifications in LCA, by reviewing what simplification approaches are described in published LCA studies and to propose how these simplifications can be categorised. Our specific objectives were to:

- Objective 1: Identify and describe previously published categories of LCA simplification approaches, illustrated with some typical examples from the literature.
- Objective 2: Identify and describe any additional simplifications found in published LCA case studies that do not fall within the categories identified through Objective 1, to provide an updated list of LCA simplification approaches.

Defining a distinct terminology of approaches of simplifications done in LCA and giving examples of each approach can be the first step towards less ‘ad hoc’ reporting of simplification, which can sometimes be seen today. Our final objective aims at highlighting how and where simplification has a role in the LCA process:

- Objective 3: Map and explain the role of the different approaches of simplification in the different stages of the LCA framework.

Such an overview can give guidance to researchers/practitioners as to how they should document simplifications and explain their implications to decision-makers.

Our goal is that the results of this study may contribute to better sharing of LCA results for decision-making, through more transparent reporting, by using consistent terminology of simplifications in LCA. We do not aim to assess how simplifications affect results or give guidance on what methods to use, how to combine methods or how to simplify any specific type of study.

In this paper, the term ‘simplified LCA’ encompasses all kinds of approaches in which the LCA study is simplified in some way relative to a full LCA, including approaches previously described as streamlining and screening. The scope of the paper is to clarify the concept of ‘simplification approaches’ in LCA, but not to describe the methodological steps and procedures for different categories of simplification approaches.

2 Methods

The basis for this study is a systematic literature review of simplification approaches in LCA, including both previously published overviews of categories of LCA simplification approaches and LCA case studies using different simplification approaches. The PRISMA statement protocol (Moher et al. 2009) was used to minimise the risk of bias, increase scientific validity and provide guidelines for conducting the review. As PRISMA was developed for systematic literature review in the health sector, some items in the checklist were not directly applicable here. Therefore, the list was slightly modified to fit the aim of a literature review of simplified LCA approaches. The PRISMA screening step is referred

Fig. 1 Identification, scanning, eligibility and inclusion of documents according to PRISMA flow diagram, adapted from Moher et al. (2009)

Fig. 2 The search string used to identify documents in Scopus

to here as scanning to avoid confusion with the LCA simplification approach.

The PRISMA statement contains a four-phase flow diagram (Fig. 1). The study’s first step was a literature search to identify documents on simplification in LCA. The search was performed on 19 June 2019 in the Scopus database (Elsevier, 2019) using the ‘Title Abstract Keywords’ fields. The intention was to include LCA studies and all associated terminology and plural forms; see Fig. 2 for the search string. The search was not limited in time but covered all literature of the included databases meeting the search criteria.

The first database search found over 1700 documents. Initial scanning of the documents revealed that all kinds

of ‘simplifications’ were identified in the studies, e.g. simplified assumptions, simplified case studies, data gathering, screening of microalgae and screening of LCA literature. To be able to focus on LCA studies using simplified approaches, the search string was modified to include documents with the *simplified term* within four words of the *LCA term*; see Fig. 2.

The identified documents encompassed various types of literature, such as books and peer-reviewed scholarly journal papers (articles, reviews, and conference proceedings) published until June 2019. The Scopus database search identified 575 documents, and 18 additional documents were identified using snow-balling (i.e. scanning central studies for cited [backward] and citing [forward] studies to find further relevant documents). This way, some early publications that had not been indexed and were not available on-line, but that otherwise matched the search criteria, were also identified. Six duplicate documents were removed.

In the scanning step, 587 documents (title, abstract and keywords) were scanned, and 34 documents were excluded because they were not relevant (i.e. the studies were not on environmental LCA). Next, the defined eligibility criteria (inclusion/exclusion criteria) were applied; see the inclusion criteria list in Fig. 3.

Studies claiming to use an LCA simplification without further describing the simplification approach were excluded (8 studies), with an exception for screening studies (see last inclusion criteria). These documents were included but lack the additional identification of simplification approaches, other than ‘screening’.

The abstracts or full text of 553 documents were reviewed, and 76 documents were excluded due to not meeting the inclusion criteria. Examples of excluded documents are articles on education of undergraduate design class, economic analysis of energy, metallurgy and risk assessments. After these steps, the 477 remaining studies were included in the qualitative analysis.

The first objective was to identify and describe different previously published categories of LCA simplification approaches. These were compiled and organised to give an overview of similarities and differences between simplification approaches. The identified documents were then grouped according to what simplification approach was used or described in the case studies. Selections of ‘typical’ studies were chosen to exemplify each different approach. After this, a number of case studies remained that were not possible to categorise as belonging to any of the established categories of simplification approaches. These were analysed further as part of the second objective.

The second objective was to complement the previously published simplification categories with any additional simplification approaches found through the literature search. This was achieved by grouping all simplification approaches that did not fit with the previously identified categories, which resulted in four additional categories that were added to an extended, revised list of simplification approach categories. Some typical studies were also chosen to exemplify these additional categories of simplification approaches.

Finally, to meet the third objective, the identified categories of LCA simplification approaches were analysed with an LCA process perspective, by mapping where in the LCA

Fig. 3 Inclusion criteria used in the literature search

workflow they are to be introduced and what stage in the life cycle framework is affected.

3 Results and analysis

Several labels have developed to signify LCA simplification approaches, such as *simplified*, *streamlining*, *screening*, *partial*, *abridged*, *limited*, *fast* and *scoping* LCA. In some cases, the line between what should be considered a full LCA, simplified LCA or neither is fuzzy. This study identified ‘streamlining’, ‘screening’, and ‘simplified’ as the most common words used to describe an LCA study that has been simplified in some way.

The earliest publication explicitly mentioning the search terms for simplification and LCA was identified from 1994. Early publications mainly use the terminology ‘screening LCA’ and ‘streamlined LCA’ to describe different forms of simplification. The earliest mention of screening and streamlining LCA was found in the article by Svensson and Ekvall on fair and cost-effective ways to compare two products (Svensson and Ekvall, 1995). These approaches may have been described in earlier studies, but with other terminology, which hence are not included in this literature review.

The goal of screening LCA according to most studies, e.g. Rebitzer (2005); Svensson and Ekvall (1995), is to identify those areas of the product system and/or key aspects of the life cycle that contribute significantly to the environmental impacts of the overall system. Its main aim is not to quantify the aspects but rather identify the hot-spots and areas that should not be neglected in a complete LCA study (e.g. Andersson et al. 1998; Rebitzer 2005). Screening LCA studies aim to include the full life cycle (ibid.).

The descriptions of what is a simplified LCA vary, but it is usually described as an LCA with a more narrow scope, including fewer processes and/or fewer impact categories. Weitz et al. (1996) refer to simplified LCA as approaches to reduce scope, cost and effort required to conduct an LCA study. Svensson and Ekvall (1995) recommended that simplification should be combined with screening for a cost-effective assessment.

4 Previously published categories of LCA simplification approaches

The earliest published overview of simplification approaches, with eight different categories, is presented in a study from 1996, reporting on the state of practice based on discussion with LCA practitioners and researchers (Weitz et al. 1996). It is interesting to note that the International Organization for Standardization (ISO) issued the first international standard for LCA, providing its main principles and

framework in 1997. This indicates that the development of LCA and LCA simplification approaches was taking place in parallel. There were, for instance, different views of what constitutes a simplification in LCA. Weitz et al. (1996) claimed that simplifications could be classified into two broad categories: modifying the *methodology* and facilitating the *process* of performing an LCA. In their article, they describe approaches for what they see as streamlining methodology (ibid.). Todd et al. (1999), on the other hand, claimed that simplification is a routine element of defining the boundaries and data needs of a study, and hence, that is not in itself a different approach or methodology for LCA. In this review, we make no such distinction.

As indicated in Table 1, Weitz et al. (1996) have later been referred to by most subsequent studies with overviews of categories of simplification approaches (such as Curran and Young 1996; Hunt et al. 1998; Todd et al. 1999). Some differences can be identified when comparing these studies. No categories other than those presented already by Weitz et al. have been added over time, but some have been reorganised or removed.

Curran and Young (1996) do not include ‘Establish criteria to be used as *showstoppers* or *knockouts*’. Interestingly, the Curran and Young article reports from the EPA conference on streamlining LCA and is based on the keynote by K. A. Weitz, in which he presented only seven simplification categories. This is probably because there was no consensus on the definition of a simplifying approach, and the approaches were a work in progress.

Hunt et al. (1998) evaluated the effects of ten simplifying approaches on LCA results by applying sets of reference life cycle inventory (LCI) data for a variety of product systems and comparing results with the results of the corresponding full LCA. The categories ‘Limit or eliminate impact assessment’ and ‘Establish criteria to be used as *showstoppers* or *knockouts*’ are not included, but the authors do not comment in the report why these categories were excluded.

‘The Final Report from the SETAC North America Streamlined LCA Workgroup’ by Todd et al. (1999) is highly cited and can be considered a central study concerning LCA simplification. Compared with Weitz et al. (1996), this list does not include the two categories ‘Eliminate specific inventory parameters’ and ‘Limit or eliminate impact assessment’, but it is not commented on in the report why these categories were excluded.

Long after these early studies were published, Hung et al. (2018) note that seemingly very little exploration and development is aimed at simplification approaches and that the strategies developed in the EPA meeting (Todd et al. 1999) still are adopted but have not progressed. It is clear that simplification approaches have not developed significantly over time, although some categories have been added, some have disappeared, and approaches have been tested on a variety

Table 1 Identified simplification categories from 1996 to 1999. Similar categories, as presented by different authors, are organised in rows for ease of comparison. Grey cells indicate that the approach is not included in the specific categorisation list

Reference	Weitz et al. 1996	Curran and Young 1996	Hunt et al. 1998	Todd et al. 1999
Source of listed categories	Based on study and discussion	Weitz et al. (1996)	Weitz et al. (1996)	Weitz et al. (1996), USEPA (1997)
LCA simplification categories	Limit or eliminate life cycle stages: A. Limit or eliminate upstream stages B. Limit or eliminate downstream stages C. Limit or eliminate upstream and downstream stages Focus on specific environmental impacts or issues Eliminate specific inventory parameters Limit or eliminate impact assessment Use qualitative as well as quantitative data Use surrogate data Establish criteria to be used as 'show-stoppers' or 'knockouts' Limit the constituents studied to those meeting a threshold volume	Eliminating stages in the total life cycle Focusing the study on specific environmental impacts or issues from the outset Analysing for a limited list of inventory categories Eliminating impact assessment Using qualitative information Using surrogate data from previous studies Using 'threshold' levels to curtail analysis at specific points	A. Removal of upstream components B. Removal of partial upstream components C. Removal of downstream components D. Removal of up- and downstream components Specific entries used to represent impacts Specific entries used to represent LCI Use of qualitative or less accurate data Use of surrogate processes	A. Limiting or eliminating all or some upstream stages B. Limiting or eliminating downstream stages C. Limiting or eliminating upstream and downstream stages Focusing on specific environmental impacts or issues Using qualitative as well as quantitative data Using surrogate process data Establishing criteria to be used as showstoppers or knockouts Limiting the constituents studied to those meeting a threshold volume

of product systems to evaluate their usability. The distinction between the categories is still not defined in consensus.

After compiling previously published categories of simplification approaches, the reviewed case study documents were categorised according to the simplification approach used or described in the case studies. We judged the latest of the identified categorisation schemes (Todd et al. 1999) as being the most “mature” in terms of having handled overlaps and gaps in the previous ones, and hence base our further work on this scheme. The six categories of LCA simplification approaches are described below in order to clarify the approaches recognised by this study. Ellingsen et al. (2016) and Hung et al. (2018), who referenced these simplification approaches in their studies, inspired the wording of the category labels.

1. ***Partly or fully ignoring upstream and/or downstream processes:*** This approach includes studies known as cradle-to-gate (Magelli et al. 2009), gate-to-gate (Franze and Ciroth 2011), well-to-wheel (Van Mierlo et al. 2004) and waste LCA (Gradin et al. 2013). This simplification will limit the inventory analysis and succeeding process steps. It is used for different reasons, either when the limitation is assumed to have negligible effects on the results, when one specific life cycle area is of interest or if there are limited data available.
2. ***Narrowing the range of environmental impacts considered.*** Limiting the number of impact categories reduces the complexity of the impact assessment stage, but consequently can also simplify the inventory phase if fewer inventory parameters contribute to the selected impact categories. Narrowing the range of impact categories can be carried out by focusing on a limited number of environmental stressors. One example is Graedel (1998) who focuses on five environmental criteria in the Environmentally Responsible Product Assessment (ERPA) method (Graedel 1998). Although these five criteria can be seen as all-encompassing of environmental stressors, limiting the sheer number of criteria reduces the complexity of the impact assessment, but it does not necessarily simplify the inventory phase. It is also common to focus only on climate change (Bala et al. 2010) and energy use (Oregi et al. 2015). Although relevant impacts must be determined by the aim of the study, the simplification may also be applied due to lack of data.
3. ***Mixing qualitative and quantitative data, depending on availability.*** This approach can entail that quantitative inventory is transformed into qualitative indicators, or that qualitative inventory and impact assessment are used. An example of mixing quantitative and qualitative data is semi-quantitative assessments that combine both (Fleischer and Schmidt 1997). This simplification is applied in the inventory analysis step. In some studies, a qualitative screening was used in the early design phase of a product (Heidari et al. 2019) or as a complement to quantitative LCA (Hochschorner and Finnveden 2003). The impact assessment step can be simplified with this approach, to illustrate environmental factors that are not readily translatable to quantification, such as biodiversity and habitat issues (Todd et al. 1999). This simplification can be used if data are not readily available.
4. ***Using surrogate data*** means that processes or materials with a lack of data inventory are replaced with similar secondary data based on physical, chemical or functional similarities (Biswas and Naude 2016). The simplification is used in the inventory analysis step, while the level of data quality is determined in the goal and scope step. This approach is also referred to as *using proxy data* (Lee and Xu 2004). The effect of using secondary data on the validity of results has been tested in several studies (such as Moberg et al. 2014; Schmidt and Beyer 1998; Weitz et al. 1996). Surrogate data for the inventory can be found in databases and/or software.
5. ***Establishing ‘showstopper’ criteria that render a specific option unacceptable and further analysis irrelevant.*** This approach is applied in the inventory analysis step, through analysis of key material and process parameters. The aim of the approach is to find critical issues that may make further analysis unnecessary, for instance, in early product/process design stages or when prioritising between alternative policy strategies. Only one example of this approach was identified among the studies found in the literature review: a ‘red flag’ analysis (Joyce and Björklund 2019). The lack of other studies using this approach could be due to the fact that ‘no result’ studies are rarely published.
6. ***Limiting the constituents studied to those meeting a threshold volume.*** This approach excludes the material and energy inventory analysis to all under a set percentage. Full-scale LCAs sometimes use a threshold of 1%, while a more significant percentage may result in a simplified LCA (Todd et al. 1999). This may be seen as a sub-category of the ISO standard ‘cut-off’, using the percentage of a mass/energy flow as a proxy for its environmental significance. The disadvantage of this approach is that by focusing on only volume and disregarding toxicity etc., flows of environmental significance may be overlooked (Todd et al. 1999). In building assessments, auxiliary materials with low mass—such as nails—are usually excluded (Kellenberger and Althaus 2009). This simplification is used if there is a lack of data.

5 Simplification approaches in LCA case studies and revised categorisation

A number of simplification approaches were found in LCA studies via the literature search that did not correspond to any of the six previously published simplification approach categories. These were grouped to define additional categories, resulting in four additional categories of LCA simplification (c.f. Appendix).

The added LCA simplification approaches are described below, with examples from a few typical studies. In the cases where several simplification approaches are used in combination or in parallel, this is demonstrated by the reoccurring example studies.

7. **Cut-off.** The ISO standard (ISO 2006b) defines cut-off as excluding unit processes or product systems based on a specified amount of material or energy flow or level of environmental significance associated with that process or system. Approach 6 ‘Limiting the constituents studied’ may be seen as a sub-category of this approach, but the cut-off approach, according to ISO, explicitly considers the significance of the environmental impact. This simplification is applied in the inventory analysis, limiting the material and energy inventory, and the impact assessment step. In this simplification approach, as in approach 6, there is a “cut-off paradox”; in other words, in order to know if a process can be cut off, you must know how much the process contributes to the total impacts. To avoid this paradox, some LCA practitioners use a mass-based cut-off criterion (Hauschild et al. 2018). The cut-off is used when the limitation has negligible effects on the results, and also if there is a lack of data.
8. **Tool/database.** This is a broad category including the use of a tool, matrix, modular LCA, or database, which can simplify the gathering of data for the inventory analysis and assist in the impact assessment and interpretation steps. Although most current LCA studies use tools and databases, it is seldom recognised as a simplification in itself. It still deserves to be categorised as simplification, as it addresses the availability of data with access to complete databases or as reduced re-usable bundles, i.e. modules (Rebitzer 2005). The use of tools/databases will also almost invariably mean that other simplification approaches are used, as they are often built into tools and databases. For instance, ‘Using surrogate data’ (approach 4) could be viewed as a part of this approach, but while surrogate data only involves replacing missing data with data from similar products or processes, the Tool/Database category is vaster.

There is a significant variety of tools aimed at simplifying LCA, designed for different purposes, such as supporting the assessment through area-specific tools, like assessing active pharmaceutical ingredients and fine chemicals (Jiménez-González et al. 2013), aiding in the assessment of impacts (Bocken et al. 2012), and guiding the interpretation of results (Hofstetter et al. 2000). This simplification is used during screening studies, using area-specific databases and tools, and when there is a lack of primary data. One example of this simplification is the ERPA matrix presented by Graedel (1998).

Modules are interconnected but exchangeable units, which together can represent a full life cycle (Steubing et al. 2016). This approach includes other research area-specific databases, like GHG for different food categories (Clune et al. 2017), used to simplify an LCA study. Modular LCA can be used to adapt available data to similar cases, as in Roches et al. (2010) where agriculture data was adjusted using modules to fit another study. Modular LCA enables a simplified investigation of scenarios and trade-offs among different decision parameters (Feiz et al. 2015; Jungbluth et al. 2000).

9. **Comparative LCA with omission of identical elements.** This approach is possible if two or more products being compared have identical elements (the same processes of the same magnitude), such as life cycle phases, materials or processes. The identical elements can be omitted, and the difference in impacts can be assessed. This approach was mentioned as an ‘obvious’ simplification by Svensson and Ekvall (1995) and limited the comparative inventory analysis. In the SETAC report, this simplification approach is given as one example (Christiansen et al. 1997). This simplification resembles approach 1 ‘Limiting up- or downstream processes’ and 7 ‘Cut-off’ but is justified by being a comparative study. It is important to note that the results of such a study are relative and not absolute, i.e. the omission of one or more identical parts means that the total impacts of the compared systems are not quantified. Therefore, this approach cannot be used when a goal is the identification of hot-spots within each system or comparison to the magnitude of other systems. In a study by Kellenberger and Althaus (2009), identical materials and processes of building components are excluded, with the aim to analyse the relevance of simplifications in LCA of building components. When comparing different vehicle components, such as an exterior panel (Poulidikidou et al. 2016) or drivetrains (Gradin et al. 2018), it is possible to omit all other vehicle parts that are identical in order to focus on the component in question.

10. **Screening** is aimed at finding key issues without quantifying them in detail (see, for example, Rebitzer 2005; Svensson and Ekvall 1995). In general, screening is applied in the inventory analysis steps, usually covering the entire life cycle with lower data quality, for instance through evaluation of similar product systems or broad product categories encompassing the product of interest. It is advisable to assess several impact categories in order to minimise the risk of leaving out potential hot-spots. Examples of such studies include Thrane's (2006) screening of a variety of fish products, Moberg et al. (2010) screening comparison of printed and e-paper newspapers and Bretz and Frankhauser's (1996) evaluation of chemicals. This approach can be implemented due to lack of data.

While Christiansen et al. (1997) views screening as a part of LCA simplifications, many have described screening not as an LCA simplification approach, but as an application of LCA results (Todd et al. 1999; Weitz et al. 1996). This may be the reason screening was not included in any of the previously published summaries of LCA simplification

approaches. We have chosen in this review to categorise screening as a simplification approach because of its explicit focus on finding key issues while accepting simplifications as lower data quality, and the possibility of qualitative assessment. In the review, some studies were found that stated only screening as the simplification approach.

The difference between some categories might at first glance seem insignificant—for example, between approach 6 'limiting the constituents studied' and approach 7 'cut-off'. To clarify differences and motivate their definition as separate categories, some important characteristics of the categories are highlighted in Table 2. The table summarises the complete list of simplification approaches, along with brief comments on how the simplification is expressed in an LCA model (application), typical reasons for applying it and in how many instances it was encountered in the reviewed literature. 'Lack of data', which clearly stands out as the most common reason for simplification, obviously can also be a matter of lack of time and resource to collect data.

Among the 477 documents identified through the literature search, the most frequently described simplification approaches were 'narrowing the range of environmental

Table 2 LCA simplification approaches, described in terms of application, the reason for each simplification and the number of case studies identified belonging to each approach

	Simplification category	Application	Reason for implementation	Number of studies
1	Partly or fully ignoring upstream and/or downstream processes	Limit the system boundaries and subsequent inventory analysis	<ul style="list-style-type: none"> • Lack of data • Focus on specific life cycle phase(s) 	144
2	Narrowing the range of environmental impacts considered	Limit impact assessment categorisation	<ul style="list-style-type: none"> • Lack of data • Focus on specific impact(s) 	231
3	Mixing qualitative and quantitative data	Quantitative inventory translated to qualitative indicators or qualitative inventory and impact assessment	<ul style="list-style-type: none"> • Lack of data • Assess the impacts that are difficult to quantify 	41
4	Using surrogate process data	Use of database or software for LCI	<ul style="list-style-type: none"> • Lack of data 	35
5	Establishing showstopper criteria	Analysis of key material and process parameters in LCI, related to a set threshold criterion	<ul style="list-style-type: none"> • Identifying critical issues 	1
6	Limiting the constituents studied to those meeting a threshold volume	Limit material and energy inventory analysis to a set threshold volume	<ul style="list-style-type: none"> • Lack of data 	41
7	Cut-off	Limit material and energy inventory analysis, excluding processes, limit impact assessment according to a set threshold volume	<ul style="list-style-type: none"> • Lack of data • Elements with insignificant impacts 	18
8	Tool/database	Use database, tool or software for LCI, LCIA or Interpretation	<ul style="list-style-type: none"> • Lack of data • Screening • Area-specific tools/modules available 	213
9	Comparative LCA with the omission of identical elements	Limit comparative inventory analysis	<ul style="list-style-type: none"> • Lack of data • Strict comparison allows omission of identical parts 	21
10	Screening	Assess complete LC, lower data quality in LCI, several impact categories	<ul style="list-style-type: none"> • Lack of data • Find key issues • Strict screening allows the use of data of lesser quality 	121

impacts considered’ and ‘tool/database’. Just over half of the reviewed studies describe the use of two or more simplification approaches, which is why the total number of occurrences listed in Table 2 exceeds 477 (see Fig. 4). Almost 80% of the studies describe the use of one to two simplifications. There is no apparent pattern concerning what simplification approaches are used simultaneously. In this study, however, we have not looked into how different fields, using LCA, prefer to use simplifications, e.g. agriculture, chemistry and design-process.

6 The role of simplification approaches in the LCA process

The final objective was to indicate how and where simplification approaches have a role in the LCA process, which may assist in more transparent documentation and explanation of the simplification approaches used in a specific study. The simplifications are iterative and influence one another; for example, if the inventory analysis is limited by a simplification, this will influence the impact assessment step and vice versa. The different categories of simplification are mapped and explained in the different stages of the LCA framework, as shown in Fig. 5.

The goal and scope definition step is central to any simplification approach, as a study is valid if the degree of incompleteness is in line with the goal and scope (European Commission 2010). Hence, most forms of simplification approaches should be determined by the goal and scope definition but will affect the LCA process in one or more subsequent steps. As for any other methodological choice, motivation for the simplification approaches used should be explained in this step.

Fig. 5 Simplification approaches mapped in the iterative LCA process perspective

Fig. 4 The number of simplification approaches described per reviewed study

The most labour-intensive step of LCA is usually inventory analysis, collecting and compiling data on the elementary flows. As such, it is the step most in need of simplification. Nine of the ten simplification approaches could be of use in this step: (1) ‘partly or fully ignoring upstream or downstream processes’, (3) ‘mixing qualitative and quantitative data’, (4) ‘using surrogate data’, (5) ‘establish “showstopper” criteria’, (6) ‘limiting the constituents studied’, (7) ‘cut-off’, (8) ‘tool/databases’, (9) ‘comparative LCA with the omission of identical elements’ and (10) ‘screening’. In the impact assessment step, four simplification approaches were of relevance: (2) ‘narrowing the range of environmental impacts considered’, (3) ‘mixing qualitative and quantitative data’, (7) ‘cut-off’ and (8) ‘tool/database’.

Only one simplification was relevant to the interpretation step (including identification of significant issues, checking of completeness, sensitivity and consistency, and providing conclusions, limitations, and recommendations): (8) ‘tool/database’.

7 Discussion and conclusions

7.1 Categories for simplification in LCA

The aim of this paper was to perform a systematic literature review to investigate the common understanding of simplifications in LCA and to propose how these simplifications can be categorised, with the overall goal to contribute to better sharing of LCA results for decision-making through more transparent reporting. Our first objective was to identify and describe approaches that span the variety of simplifications in previously published categorisations. We found that early overviews of simplified approaches, published between 1996 and 1999, are still the most frequently referenced. The early discussions about simplifications contributed essential parts to the development of the first LCA standard, such as the specific considerations and investigations of what should be included and reported in a complete LCA study.

Six categories of simplification approaches were selected from the previously published categories (‘partly or fully ignoring upstream and/or downstream processes’, ‘narrowing the range of environmental impacts considered’, ‘mixing qualitative and quantitative data, depending on availability’, ‘using surrogate data’, ‘establishing “showstopper” criteria’, and ‘limiting the constituents studied to those meeting a threshold volume’). All of these build, directly or indirectly, on the ones described by Todd et al. (1999). Not all simplification approaches found in our review fit into these six previously published simplification categories, and our second objective was to complement with any additional categories needed to represent simplifications found in published LCAs. Four additional categories were identified and

described (‘cut-off’, ‘tool/databases’, ‘comparative LCA with the omission of identical elements’, and ‘screening’). In all, a total of ten simplification approaches were identified and described in this study (Table 2).

The different categories of simplification approaches are not mutually exclusive. There are overlaps and diffuse boundaries between categories. The category tools/database is an obvious example of this, as tools and databases may have other simplifications integrated into their design. Although not within the scope of this paper, further separation of categories could improve the clarity of documentation, but at the same time make it more difficult to place one approach in one or the other category. In the end, it is not certain that this would be helpful towards the end that is the overall goal of this paper, better sharing of LCA results for decision-making through more transparent reporting.

Our third objective was to illustrate the role of the identified simplification approaches in the different stages of the LCA framework. Examination of the documents included in this review supports the idea that simplifications in LCA are often motivated by a lack of data. Hence, it was not surprising that most simplification approaches are aimed at reducing the effort in the inventory step, which is typically the most time and resource-demanding step of LCA. While the mapping of approaches along the LCA process is not a major contribution of this paper, we believe its visualisation is of value and contributes to our overall aim of more transparent communication of simplification.

The results of this study strengthen the concerns regarding inconsistencies in LCA simplification terminology and how well simplifications are described in individual studies. This means that the rightmost column in Table 2 is not a measure on the most frequently used simplification approaches, but most *mentioned* in simplified studies. Although the EPA report (Todd et al. 1999) is often cited, many simplified studies were found that did not refer to this or any other categories of simplification to explain the simplification approaches that they apply. As pointed out already by Weitz and Sharma (1998), a key challenge for the LCA practitioner is to ensure that the choice of simplification approach is consistent with the study goal and that the subsequent results will be adequate to support that goal. Weitz and Sharma make an attempt at formalising what aspects to consider to ensure this (type of analysis required to meet study goals, intended use of results, intended audience, the role of recycling, dominance of manufacturing and more) (ibid.). They also point out that “The more the study team knows about the product or process under study, the more confidence they can have in making streamlining decisions” (ibid., p.84) and that the motivation for the choice must also be communicated to the decision-maker and audience for the study. Still, simplifications are rarely justified to the same degree as other methodological choices, or

evaluated regarding whether the approach is appropriate for the intended purpose of the study. Further, multiple simplification approaches are often used in one study. While this in itself is not a problem, it makes interpretation of results more complex and puts even higher demands on terminology and transparency when explaining the simplifications that have been done to explain the validity and limitations of results.

8 Limitations

Rigorous design of the literature search, as in this study, has its pros and cons. While the method makes the search transparent and repeatable, there is a risk of missing valuable information that is not covered by the search string. To reduce this risk, we used snow-balling to reach beyond what was found in the database search. This, however, does not help as long as other terminology is used in published material. Possibly other valuable material could be added through search techniques (interviews or questionnaires). We still believe that our coverage is rather good. Some areas of the ‘LCA ecosystem’ were, however, deliberately left out in the literature search. LCA-based approaches have evolved over the years that do not identify strictly as LCA (e.g. Eco-design and foot printing). This is good, as LCA should be used in ways that make sense for the particular application. However, it does make it difficult to draw a clear line between what is LCA and not LCA. We delimited our search to studies identifying as ‘LCA’. We believe that there is something good in letting LCA be at the core of this development, and our interest revolved around the common practice of simplification in LCA.

A collection of approaches to estimate missing inventory data that may play a role in the future, but that were not covered by the literature review, are multivariate statistical or machine learning techniques to derive inventory data based on known properties of substances and processes. One example is the study by Song et al. (2017) that uses artificial neural networks to estimate life cycle impacts of chemicals using the information on molecular structures. This may be seen as a sub-category of simplification using proxy data, but should, if developed further, possibly be highlighted as a simplification category of its own.

9 Applications of results

There is no standard guidance as to which of the simplification approaches to apply, in what context they are appropriate, or to what extent they should be used (Hung et al. 2018). We also refrain from attempting to give such guidance in this paper. It would either be highly speculative and based on our experience require additional literature review with a different focus, or be performed as systematic testing of different simplifications in different settings. This would be far

beyond the aim and scope of this paper, which is descriptive of current approaches and terminology.

Still, although rather simple, we believe that the results of this study should be useful to researchers and practitioners with an ambition to communicate better about simplifications done in their studies. Moving away from the common practice of merely stating that an LCA study is streamlined, simplified or some other term without further explanation, but instead motivating the choice of simplification approach and explaining which steps of the LCA are affected and how to help receivers of LCA results to better interpret their meaning and relevance. As this study shows, the categories of simplification from early studies remain relevant despite the development in LCA over the years, but additional categories are needed to cover the different types of simplification being applied in LCAs. This study also highlights the lack of clear documentation of simplifications with consistent terminology, despite recommendations that have been around for a couple of decades.

Future work could include the development of a communication standard, with clear terminology as well as investigation of the applicability of different simplification approaches for different product systems and application areas. Different approaches are likely more and less suitable depending on the character of the study. Due to the wide variety of purposes, scenarios and products assessed in LCA, it is impossible to devise a one-size-fits-all approach for simplifications, as was noted already by Weitz and Sharma (1998). What is needed is not adding to the rulebook, but better transparency and better communication to decision-makers about the influence of simplification on results.

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