The Common Understanding of Simplification Approaches in Published LCA Studies – A review and mapping

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Abstract

Purpose:
The aim of this paper is to investigate the common understanding of the variety of simplifications in LCA, by reviewing what simplification approaches are used in LCA research, and how these simplifications can be categorised. This may contribute to better sharing of LCA results for decision-making, through more transparent reporting, and with consistent terminology of simplifications in LCA.

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 minimize the risk of bias, increase scientific validity, and provide guidelines for conducting the review.

Results and discussion:
The simplification approaches identified were grouped according to the element being simplified. Initially, six simplification approaches were identified based on previous categories. However, not all simplification approaches found in case studies fit into these six previously published simplification categories; these simplification approaches were therefore examined, 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. Due to the wide variety of purposes, scenarios, and products assessed, it is impossible to devise a one-size-fits-all approach for simplifications. Transparent reporting of simplification approaches used in an LCA study requires that they be described, the motivation for their use be explained, and their influence be evaluated; this will ultimately aid the study's audience in interpreting and comparing the results.

Keywords: LCA, simplification, screening, streamlining, literature review
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 industry (Toniolo et al., 2019). LCA results are typically complex and require a thorough understanding of underlying assumptions. When LCAs are 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 can be 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’s development, how to simplify it was an aspect of the methodology that 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 an exceptionally 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-off’s of the inventory is entirely acceptable and has 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 consistently documented 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 totally 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; Soust-Verdaguer et al., 2017), focus on simplification approaches in a specific research area such as agriculture, wind turbines, and livestock. There does not seem to be any 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 used in LCA research, and how these simplifications can be
categorised. This may contribute to better sharing of LCA results for decision-making, through more transparent reporting, and with consistent terminology of simplifications in LCA. Our specific objectives were to:

- **Objective 1:** Identify previously published categories of LCA simplification approaches, and describe why and how these are used with examples from the literature.

- **Objective 2:** Identify any additional categories of LCA simplification approaches necessary to represent simplifications found in published LCA case studies, but which are not covered by those identified through Objective 1, and describe why and how these are used with examples from the literature.

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.

In this paper, the term “simplified LCA” encompasses all kinds of approaches in which the LCA study is simplified in some way, including the 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.

**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 minimize 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 was referred to here as scanning to avoid confusion with the LCA simplification approach.

The PRISMA statement contains a four-phase flow diagram (Figure 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 Figure 2 for the search string.
The first database search found over 1,700 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 Figure 2.

![Diagram](image.png)

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

The identified documents encompassed various types of literature, such as books and peer-reviewed scholarly journal papers (articles, reviews, and conference proceedings) and covered a period from 1994 to June 2019. The Scopus database search identified 575 documents, and 18 additional documents were identified using snowballing (i.e., scanning central studies for cited [backward] and citing [forward] studies to find further relevant documents). 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 below:

- Simplified terms: `streamlin* OR simplify* OR screening*`
- Within four words: `"simplified terms" W/4 "LCA terms"`
- LCA terms: `lca OR “life cycle assessment” OR lci OR “life cycle inventor*” OR lcia OR “life cycle analys*”`
- Database result: 575 documents

**Figure 2** The search string used to identify documents in Scopus
Studies claiming to use an LCA simplification without further describing the simplification approach were excluded, 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. After these steps, the 477 remaining studies were included in the qualitative analysis.

The first objective was to identify 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 to achieve the second objective.

The second objective was to complement the previously listed 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 chosen to exemplify these additional categories of simplification approaches. All approaches were also described in terms of “why” (the reason for simplifying) and “how” (approach), and “where” (LCA workflow effect).

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

**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.

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 hotspots 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 goal of, or reason for, simplified LCA varies, 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.

**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.

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.

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

Curran and Young (1996) do not include “Establish criteria to be used as showstoppers or knockouts”. Interestingly, this categorisation in the Curran and Young article that reports from the EPA conference on streamlining LCA 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. The evaluation was made by applying sets of baseline Life Cycle Inventory (LCI) data for a variety of product systems and comparing results to 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 it is not commented on in the report why these categories were excluded.

“The Final Report from the SETAC North America Streamlined LCA Workgroup” by Todd et al. (1999), which is highly cited and can be considered a central study concerning LCA simplification. Compared to Weitz et al. (1996), this list did 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.

Hung et al. (2018) note that seemingly very little exploration and development are aimed at simplification approaches and that the strategies developed in the EPA meeting (Todd et al., 1999) still are adopted but has not progressed. It is clear that simplification approaches have not developed significantly over time. Even though some categories have been added, and some have disappeared, and approaches have been tested on a variety of product systems to evaluate their usability. The distinction between the categories is still not defined in consensus.

Weitz et al. (1996) claimed that simplifications could be classified into two broad categories. The first involves modifying the methodology, and the other aids the process of performing an LCA (ibid.). Todd et al. (1999), however, claimed that simplification is a routine element of defining the boundaries and data needs of a study and is not in itself a different approach or methodology for LCA.

The identified case study documents were categorised according to the simplification approach used or described in the case studies. Of the identified categorisation schemes, that by Todd et al. (1999) was identified as being the best suited to our needs. 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**, 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 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. **Narrows the range of environmental impacts considered.** This approach limits the number of impact assessment categories and, consequently, also limits the necessary inventory parameters to those contributing to the selected impact categories. Narrowing the range of impact categories can be carried out by focusing on a limited number of environmental stressors, such as the five used in the Environmentally Responsible Product Assessment (ERPA) method (Graedel, 1998). Other common simplifications are focusing 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**, can entail that quantitative inventory is transformed into qualitative indicators, or that qualitative inventory and impact assessment is 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 (Hochschornor 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).

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. 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. This is one part of the ISO standard “cut-off”, since this simplification concerns inventory of mass and energy volumes. Full-scale LCAs sometimes use a threshold of 1%, while a more significant percentage may result in a simplified LCA (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 the effects of the exclusion can be determined to be minimal, and also if there is a lack of data.

### Simplification approaches in LCA case studies and revised categorisation

Simplification approaches found in LCA studies via the literature search that did not correspond to any of the six simplification approach categories mentioned above were grouped to form additional categories, resulting in four additional categories of LCA simplification (c.f. Appendix).

In the same manner, as in the previous section, the four additional categories of LCA simplification approaches were identified with the support of what kind of simplification approach was used or described in the case studies. 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, the multi-use of simplification approaches are demonstrated by the reoccurring example studies. Since 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”—the categories are explained below (Table 2).

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 being a part of this approach, but the cut-off approach, according to ISO, also considers the significance of 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.** The use of a tool, matrix, modular LCA, or database can simplify the gathering of data for the inventory analysis, and also assist in the impact assessment and interpretation steps. This simplification addresses the availability of data with access to complete databases or as reduced re-usable bundles, i.e. modules (Rebitzer, 2005). As observed by, e.g. Weitz (1996), simplifications could be classified into two broad categories. This approach addresses the second, i.e. facilitating the process of performing an LCA, primarily by making data more readily available to LCA practitioners (ibid.).

There is a significant variety of tools aimed at simplifying LCA, and these have different aims such as supporting the assessment through area-specific tools (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 application 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 (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, 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. In the study by Kellenberger and Althaus (2009), building components are compared, and identical materials and processes are excluded. When comparing different vehicle components, such as an exterior panel (Poulikidou 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. It is advisable to assess several impact categories in order to minimise the risk of leaving out potential hotspots. Examples of such studies include Thrane’s (2006) screening of a variety of fish products, Moberg et al.’s (2010) screening comparison of printed and e-paper newspapers, and Bretz and Frankhauser’s (1996) evaluation of chemicals.

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. The arguments for categorisation of screening as a simplification approach are the explicit purpose of “finding key issues”, the acceptance of lower data quality, the possibility of qualitative assessment, and the identified studies stating only screening as a simplification approach.
Among the 477 documents identified through the literature search, the most frequently most described simplification approaches were primarily approach 2 “Narrowing the range of environmental impacts considered” and secondly approach 8 “Tool/database”.

The role of simplification approaches in the LCA process

The final objective was to indicate how and where simplification approaches has 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 like the process steps in that they 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 Figure 3.
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. It is highly beneficial, for the interpreter and reader if the motivation for the simplification approaches used is explained, and the approaches themselves are described in this step.

The most labour intensive step is usually inventory analysis, which involves 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/Database”; (9) “Comparative LCA with omissions of identical parts”; and (10) “Screening”.

The selection of LCIA method and impact categories are made, based on relevance for the study. 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”.

Finally, 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”.

**Discussion and conclusions**

The first objective was to identify approaches that span the variety of simplifications found in literature, based on previously published categorisations. This study identified the early overviews of simplified approaches by Weitz et al. (1996), Curran and Young (1996), Hunt et al. (1998), and Todd et al. (1999); these are still the most frequently referenced. Christiansen et al. (1997) was also an important contribution at the time, but unfortunately not available online which hinders the usage further. 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. Of the identified categorisation schemes, that by Todd et al. (1999) was identified as being the best suited to our needs. Ellingsen et al. (2016) and Hung et al. (2018), who referenced these simplification approaches in their studies, inspired the wording of the category labels.

The second objective was to complement with any additional categories needed to represent simplifications found in published LCA case studies and to give examples from the literature on the different categories of simplification. The simplification approaches were differentiated through an exploration of the reasons, application, and where in the LCA process the simplifications had an effect. Not all simplification approaches found in the study fit into these six previously published simplification categories; these simplification approaches were therefore examined, and four additional categories were identified. These categories (approaches 7 to 10) were “Cut-off”, “Tool/Databases”, “Comparative LCA with the omission of identical elements”, and “Screening”. A total of ten simplification approaches were identified in this study.

The third objective was to map and explain the role of the identified simplification approaches in the different stages of the LCA framework. The first step in the LCA process is central for simplifications since the construction of the goal and scope guide the accuracy level. Most simplification approaches are aimed at reducing the effort in the inventory step. The mapping gave an overview of where in the LCA framework the simplification approaches give effect.

Examination of the documents included and revised simplification approaches supports the idea that simplifications in LCA are often motivated by a lack of data. Simplification is most often aimed at reducing the inventory analysis effort.

Additionally, findings strengthen the concern regarding significant inconsistencies in LCA simplification terminology, and how well it is described in individual studies. This means that the final column in Table 2 is not a measure on the most frequently used simplification approaches, but most described in simplified studies. Although the EPA report (Todd et al., 1999) is often cited, many studies were found that did not refer to it or any other simplification approach list (see, for example, Table 1) in order to clarify the simplification approach applied. 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, 1998). The motivation for the choice must also be communicated to the decision-maker and audience for the study. The simplifications are rarely justified to the same degree as other methodological choices in full LCA studies. In several studies the simplifications are not evaluated with regard to if the approach is appropriate for the intended purpose of the study. Additionally, caution should be used when more than one simplification approach is used. There is a risk of arbitrary and subjective choices of simplification approaches—for example, it is unclear how many impact categories are enough to constitute a full versus a simplified LCA study (Bala et al., 2010).

We must move away from the common practice of merely stating that an LCA study is streamlined, simplified, or some other term without further explanation. Researchers need to define how the LCA is simplified, what motivates the choice of simplification approach, and which steps of the LCA are affected and how. In order to facilitate this, some sort of common LCA simplification terminology and reporting standards are needed. Including simplification approaches in the ISO standard could be one way to ensure higher quality simplified studies and improve the ability to interpret them and compare results. 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 noted already by Weitz and Sharma (1998).

This review should serve as a guide to further investigation and development for LCA practitioner interested in improving the transparency in simplified studies. Future research could investigate the connection between different simplification approaches, product systems, and research areas. Although there is no universal simplification, there are approaches that are more and less suitable depending on the character of the study. 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).
References

Andersson, K., Ohlsson, T., Olsson, P., 1998. Screening life cycle assessment (LCA) of tomato ketchup: A case study. J. Clean. Prod. 6, 277–288.

Arzoumanidis, I., Raggi, A., Petti, L., Zamagni, A., Magazzeni, D., 2013. Chapter 6. A model of simplified life cycle assessment for agri-food SMEs, in: Product-Oriented Environmental Management Systems (POEMS): Improving Sustainability and Competitiveness in the Agri-Food Chain with Innovative Environmental Management Tools. pp. 123–150. https://doi.org/10.1007/978-94-007-6116-2_6

Arzoumanidis, I., Salomone, R., Petti, L., Mondello, G., Raggi, A., 2017. Is there a simplified LCA tool suitable for the agri-food industry? An assessment of selected tools. J. Clean. Prod. 149, 406–425. https://doi.org/10.1016/j.jclepro.2017.02.059

Bala, A., Raugei, M., Benveniste, G., Gazulla, C., Fullana-I-Palmer, P., 2010. Simplified tools for global warming potential evaluation: When “good enough” is best. Int. J. Life Cycle Assess. 15, 489–498. https://doi.org/10.1007/s11367-010-0153-x

Biswas, W.K., Naude, G., 2016. A life cycle assessment of processed meat products supplied to Barrow Island: A Western Australian case study. J. Food Eng. 180, 48–59. https://doi.org/10.1016/j.jfoodeng.2016.02.008

Bocken, N.M.P., Allwood, J.M., Willey, A.R., King, J.M.H., 2012. Development of a tool for rapidly assessing the implementation difficulty and emissions benefits of innovations. Technovation 32, 19–31. https://doi.org/10.1016/j.technovation.2011.09.005

Bretz, R., Frankhauser, P., 1996. Screening LCA for large numbers of products: Estimation tools to fill data gaps. Int. J. Life Cycle Assess. 1, 139–146. https://doi.org/10.1007/BF02978941

Christiansen, K., de Beaufort-Langeved, A., van den Berg, N., Haydock, R., TenHouten, M., Kotaji, S., Oerlemans, E., Schmidt, W.-P., Strandroff, H., Weidenhaupt, A., White, P., 1997. Simplifying LCA: Just a Cut? SETAC Europe Screening and Streamlining Working Group.

Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766–783. https://doi.org/10.1016/j.jclepro.2016.04.082

Collet, P., Lardon, L., Steyer, J.P., Hélias, A., 2014. How to take time into account in the inventory step: A selective introduction based on sensitivity analysis. Int. J. Life Cycle Assess. 19, 320–330. https://doi.org/10.1007/s11367-013-0636-7

Curran, M.A., Young, S., 1996. Report from the EPA conference on streamlining LCA. Int. J. Life Cycle Assess. 1, 57–60. https://doi.org/10.1007/BF02978640

Ellingsen, L.A., Singh, B., Stromman, A.H., 2016. The size and range effect: Lifecycle greenhouse gas emissions of electric vehicles. Environ. Res. Lett. 11. https://doi.org/10.1088/1748-9326/11/5/054010

Elsevier, 2019. Scopus [WWW Document]. URL https://www.scopus.com (accessed 10.20.19).

European Commission, 2010. International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. Luxembourg. https://doi.org/10.2788/38479

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., Marshall, R., 2015. Improving the CO2 performance of cement, part I: Utilizing life-cycle assessment and key performance indicators to assess development within the cement industry. J. Clean. Prod. 98, 272–281. https://doi.org/10.1016/j.jclepro.2014.01.083

Fleischer, G., Schmidt, W.P., 1997. Iterative screening LCA in an Eco-Design tool. Int. J. Life Cycle Assess. 2, 20–24. https://doi.org/10.1007/BF02978711

Franze, J., Ciroth, A., 2011. A comparison of cut roses from Ecuador and the Netherlands. Int. J. Life Cycle Assess. 16, 507–515. https://doi.org/10.1007/s11367-011-0268-0
Assess. 16, 366–379. https://doi.org/10.1007/s11367-011-0266-x

Gradin, K.T., Luttropp, C., Björklund, A., 2013. Investigating improved vehicle dismantling and fragmentation technology. J. Clean. Prod. 54, 23–29. https://doi.org/10.1016/j.jclepro.2013.05.023

Gradin, K.T., Poulikidou, S., Björklund, A., Luttropp, C., 2018. Scrutinising the electric vehicle material backpack. J. Clean. Prod. 172. https://doi.org/10.1016/j.jclepro.2017.12.035

Graedel, T.E., 1998. Streamlined Life-Cycle Assessment. Prentice Hall International, London.

Guinée, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T., 2011. Life cycle assessment: past, present, and future. Environ. Sci. Technol. 45, 90–96. https://doi.org/10.1021/es101316v

Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I., 2018. Life Cycle Assessment - Theory and Practice. Springer. https://doi.org/10.1007/978-3-319-56475-3

Heidari, M.D., Mathis, D., Blanchet, P., Amor, B., 2019. Streamlined life cycle assessment of an innovative bio-based material in construction: A case study of a phase change material panel. Forests 10, 1–16. https://doi.org/10.3390/f10020160

Henriksen, T., Astrup, T.F., Damgaard, A., 2018. Linking Data Choices and Context Specificity in Life Cycle Assessment of Waste Treatment Technologies: A Landfill Case Study. J. Ind. Ecol. 22, 1039–1049. https://doi.org/10.1111/jiec.12709

Henriksen, T., Levis, J.W., Barlaz, M.A., Damgaard, A., 2019. Approaches to fill data gaps and evaluate process completeness in LCA—perspectives from solid waste management systems. Int. J. Life Cycle Assess. 1587–1601. https://doi.org/10.1007/s11367-019-01592-z

Hochschorner, E., Finnveden, G., 2003. Evaluation of two simplified life cycle assessment methods. J. Life Cycle Assess. 8, 119–128.

Hofstetter, P., Braunschweig, A., Mettler, T., Müller-Wenk, R., Tietje, O., 2000. The Mixing Triangle: Correlation and Graphical Decision Support for LCA-based Comparisons. J. Ind. Ecol. 3.

Hung, C.R., Ellingsen, L.A.W., Majeau-Bettez, G., 2018. LiSET: A Framework for Early-Stage Life Cycle Screening of Emerging Technologies. J. Ind. Ecol. 00, 1–12. https://doi.org/10.1111/jiec.12807

Hunt, R.G., Boguski, T.K., Weitz, K., Sharma, A., 1998. Case studies examining LCA streamlining techniques. Int. J. Life Cycle Assess. 3, 36–42. https://doi.org/10.1007/BF02978450

ISO, 2006a. ISO 14040:2006. Environmental Management: Life Cycle Assessment, Principles and Framework.

ISO, 2006b. Environmental management – Life cycle assessment – Requirements and guidelines - ISO 14044:2006.

Jiménez-González, C., Ollech, C., Pyrrz, W., Hughes, D., Broxterman, Q.B., Bhatheila, N., 2013. Expanding the boundaries: Developing a streamlined tool for eco-footprinting of pharmaceuticals. Org. Process Res. Dev. 17, 239–246. https://doi.org/10.1012/op3003079

Jungbluth, N., Tietje, O., Scholz, R.W., 2000. Food purchases: Impacts from the consumers’ point of view investigated with a modular LCA. Int. J. Life Cycle Assess. 5, 134–142. https://doi.org/10.1007/BF02978609

Kellenberger, D., Althaus, H.J., 2009. Relevance of simplifications in LCA of building components. Build. Environ. 44, 818–825. https://doi.org/10.1016/j.buildenv.2008.06.002

Lee, S.G., Xu, X., 2004. A Simplified Life Cycle Assessment of Re-usable and Single-use Bulk Transit Packaging. Packag. Technol. Sci. 17, 67–83. https://doi.org/10.1002/pts.643
Magelli, F., Boucher, K., Bi, H.T., Melin, S., Bonoli, A., 2009. An environmental impact assessment of exported wood pellets from Canada to Europe. Biomass and Bioenergy 33, 434–441. https://doi.org/10.1016/j.biombioe.2008.08.016

McManus, M.C., Taylor, C.M., 2015. The changing nature of life cycle assessment. Biomass and Bioenergy 82, 13–26. https://doi.org/10.1016/j.biombioe.2015.04.024

Mendecka, B., Lombardi, L., 2019. Life cycle environmental impacts of wind energy technologies: A review of simplified models and harmonization of the results. Renew. Sustain. Energy Rev. 111, 462–480. https://doi.org/10.1016/j.rser.2019.05.019

Moberg, Å., Borggren, C., Ambell, C., Finnveden, G., Guldbrandsson, F., Bondesson, A., Malmodin, J., Bergmark, P., 2014. Simplifying a life cycle assessment of a mobile phone. Int. J. Life Cycle Assess. 19, 979–993. https://doi.org/DOI 10.1007/s11367-014-0721-6

Moberg, Å., Johansson, M., Finnveden, G., Jonsson, A., 2010. Printed and tablet e-paper newspaper from an environmental perspective - A screening life cycle assessment. Environ. Impact Assess. Rev. 30, 177–191. https://doi.org/10.1016/j.eiar.2009.07.001

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D’Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., Gotzsche, P.C., Grimshaw, J., Guyatt, G., Higgins, J., Ioannidis, J.P.A., Kleijnen, J., Lang, T., Magrini, N., McNamara, D., Moja, L., Mulrow, C., Napoli, M., Oxman, A., Pham, B., Rennie, D., Sampson, M., Schulz, K.F., Shekelle, P.G., Tovey, D., Tugwell, P., 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement (Chinese edition). J. Chinese Integr. Med. 7, 889–896. https://doi.org/10.3736/jcim20090918

Oregi, X., Hernandez, P., Gazulla, C., Isasa, M., 2015. Integrating simplified and full life cycle approaches in decision making for building energy refurbishment: Benefits and Barriers. Buildings 5, 354–380. https://doi.org/10.3390/buildings5020354

Overcash, M.R., 1994. Cleaner technology life cycle methods: European research and development 1992–1994. Hazard. Waste Hazard. Mater. 11, 459–478.

Poulikidou, S., Jerpdal, L., Björklund, A., Åkermo, M., 2016. Environmental performance of self-reinforced composites in automotive applications - Case study on a heavy truck component. Mater. Des. 103, 321–329. https://doi.org/10.1016/j.matdes.2016.04.090

Rebitzer, G., 2005. Enhancing the application efficiency of life cycle assessment for industrial uses. https://doi.org/10.1065/lca2005.11.005

Roches, A., Nemecek, T., Gaillard, G., Plassmann, K., Sim, S., King, H., Milà i Canals, L., 2010. MEXALCA: A modular method for the extrapolation of crop LCA. Int. J. Life Cycle Assess. 15, 842–854. https://doi.org/10.1007/s11367-010-0209-y

Schmidt, W.P., Beyer, H.M., 1998. Life cycle study on a natural fibre reinforced component. SAE Tech. Pap. https://doi.org/10.4271/982195

Soust-Verdaguer, B., Llatas, C., Garcia-Martinez, A., 2017. Critical review of bim-based LCA method to buildings. Energy Build. 136, 110–120. https://doi.org/10.1016/j.enbuild.2016.12.009

Steubing, B., Mutel, C., Suter, F., Hellweg, S., 2016. Streamlining scenario analysis and optimization of key choices in value chains using a modular LCA approach. Int. J. Life Cycle Assess. 21, 510–522. https://doi.org/10.1007/s11367-015-1015-3

Svensson, G., Ekvall, T., 1995. LCA - A fair and cost effective way to compare two products? SAE Tech. Pap. https://doi.org/10.4271/951827

Thrane, M., 2006. LCA of Danish fish products: New methods and insights. Int. J. Life Cycle Assess. 11, 66–74. https://doi.org/10.1065/lca2006.01.232
Todd, J.A., Curran, M.A., Weitz, K., Sharma, A., Vigon, B., Price, E., Norris, G., Eagan, P., Owens, W., Veroutis, A., 1999. Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup. Environ. Toxicol. 31.

Toniolo, S., Mazzi, A., Simonetto, M., Zuliani, F., Scipioni, A., 2019. Mapping diffusion of Environmental Product Declarations released by European program operators. Sustain. Prod. Consum. 17, 85–94. https://doi.org/10.1016/j.spc.2018.09.004

Van Mierlo, J., Timmermans, J.M., Maggetto, G., Van den Bossche, P., Meyer, S., Hecq, W., Govaerts, L., Verlaak, J., 2004. Environmental rating of vehicles with different alternative fuels and drive trains: A comparison of two approaches. Transp. Res. Part D Transp. Environ. 9, 387–399. https://doi.org/10.1016/j.trd.2004.08.005

Weitz, K.A., Sharma, A., 1998. Practical life cycle assessment through streamlining. Environ. Qual. Manag. 7, 81–87. https://doi.org/10.1002/tqem.3310070408

Weitz, K.A., Todd, J.A., Curran, M.A., Malkin, M.J., 1996. Streamlining Life Cycle Assessment: Considerations and a report on the state of practice. Int. J. Life Cycle Assess. 1, 79–85. https://doi.org/10.1007/bf02978650